WATER POWER

A technical journal devoted to the study of all aspects of Hydro-electric developments

Annually 35 shillings by post. Single Copies 2s. 6d.

Volume 6. Number 8.

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PUBLISHED BY TOTHILL PRESS LIMITED

33 Tothill Street, Westminster, London, S.W.1

Telegrams: Trazette, Parl, London. Telephone : Whitehall 9233 (12 lines).

MANCHESTER: Century House, St. Peter's Square. Telephone : Central 3101.
BIRMINGHAM: 90 Hagley Road, Edgbaston. Telephone : Edgbaston 2466.
NEWCASTLE-ON-TYNE: 21 Mosley Street. Telephone : 22239.
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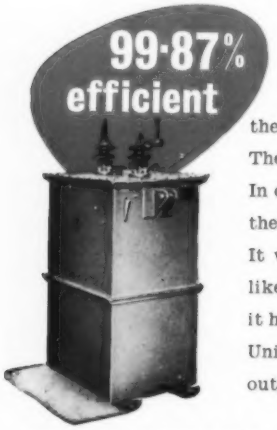

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WATER POWER

A technical journal devoted to the study of all aspects of Hydro-Electric Development

Rain Stimulation

ONE of the earliest experiments in rain stimulation known to the editorial staff of this journal took place many years ago during a severe drought in the North of England, when a certain Nonconformist minister prayed passionately for rain. The following week there were thunderstorms, torrential rain and floods, with considerable consequential damage—so much so that on the following Sunday during prayer, the minister in question was moved to exclaim, "Oh Lord, this is ridiculous!"

Whether the efforts of our artificial-rain stimulators will ever be attended by such overwhelming results is an open question. Indeed, the present-day problem is much more that of assessing how much rain is due to a given campaign of cloud seeding and how much would have fallen anyhow. Weather is subject to so many vagaries, and there are such variations, not only in the course of the year but from one year to another, that it is outstandingly difficult to establish a norm by which comparisons can be made. Doubtless this is one reason for much of the scepticism that exists in some quarters—a scepticism that is best dispelled by the development of a scientifically sound technique of analysis.

Although the science of rainmaking is still young, progress in establishing reliable methods of analysis has been much more pronounced than is generally realised. Some of these methods are significantly similar to those employed by water-power engineers in assessing natural rainfall and run-off in areas destined for hydro-electric development, one of the most promising being comparison with "control" areas having substantially similar weather characteristics. Another line of approach is to collate the records of past storms for as long a period as they are available, and to compare the progress of a seeded storm with that of a previous similar storm that had not been seeded. A valuable tool in this type of analysis is the theory of probability, and with its aid the case for rain stimulation can be said to have been demonstrated, at least on a qualitative basis. Quantitative assessment, of course, is much more difficult, but even here progress is by no means negligible.

The more we are able to draw reliable quantitative conclusions from our data the easier it will be to resolve some of the many controversies that now rage around this subject. There are those, for instance, who consider that the weather at any time and place is predetermined by a complex of natural conditions, and that artificial seeding can never produce more than a trivial result, local and ephemeral in nature. Others believe that cloud seeding exerts a kind of trigger action which can produce results quite out of proportion to the forces directly employed, substantially altering the course of unassisted nature. Certainly, methods that yield striking results in one instance may prove very disappointing in another, and the degree of success is found to depend in large measure on climatic conditions that vary widely from place to place and from time to time. On one point there is common agreement—that no results can be expected from seeding a cloudless sky; the moisture must be there before it can be brought down. Rain stimulation appears to act to greatest advantage in those marginal conditions in which there is abundant cloud but little natural precipitation.

Unfortunately the many uncertainties inherent in this young science expose it to the danger of charlatanism. It is all too easy to make vague and extravagant claims, bolster them up with pseudo-scientific jargon, and to use the difficulty of analysing results to confuse the issue. We gather that something of this kind is causing concern amongst the reputable practitioners in the United States—a country to which we owe much of the initiative for the development of this new science—and that the repute of artificial-rainmaking is being endangered in consequence. Be that as it may, an obvious guarantee of good faith is to be found in membership of the American Meteorological Society, the Royal Meteorological Society in Great Britain, or the appropriate body in any other country concerned.

That this new science of rainmaking is engaging

the serious attention of the United States is evidenced by the recent appointment of a National Advisory Committee on Weather Control, under the chairmanship of Captain Howard T. Orville, and numbering among its members Mr. Lewis Douglas, a former highly popular U.S. Ambassador to Great Britain. This committee, established with a two-year life, is charged with the thorough review and study of all aspects of the question of weather control, and is to report on the matter to Congress, together with recommendations as to appropriate legislation. We understand that the committee has the full confidence of the American meteorological profession, and although it is not likely to reach final conclusions as to the case for precipitation stimulation, it will undoubtedly lay a stable foundation on which to build for the future.

Many of the points to which we have referred are discussed fully and competently in the article "Ours or Theirs?" which we publish elsewhere in this issue, from the pen of Dr. Wallace E. Howell, the principal of a Massachusetts firm of meteorologists who have specialised in this work for a number of years. Dr. Howell's previous article, "Rainfall Stimulation for Hydro-Electric Power," published in our January 1954 issue, gave an account of practical procedures in cloud seeding, and aroused considerable interest. In the present article he discusses the complex question of evaluating results, and explains the various methods of analysis that have been employed. In the light of these analyses Dr. Howell is able to show that the results obtained by artificial weather control are significant. The two articles, indeed, combine to present a most useful survey of the present stage of development of this new science.

Much, if not most, of the work on weather control has been undertaken to assist agriculture, but its relevance to hydro-electric development is obvious, and we understand that weather control has already been called into service for this purpose. Whether we shall ever arrive at the point at which results can be precisely forecast is as doubtful as our ability precisely to forecast the weather itself. Nevertheless, in spite of the popular jibe, weather forecasting has become an invaluable service to agriculture, aviation and many other activities, and it may well be that weather control will reach a similar degree of usefulness. If the bugbear of drought years can be alleviated it may be possible to modify the basic calculations for hydro-electric schemes to considerable economic advantage.

Kariba or Kafue?

IN a statement made when the Federal Parliament, Rhodesia, began its present session, Sir Godfrey Huggins, the Prime Minister, intimated that two French technologists from Electricité de France had been called upon to give a report as to whether the Kariba or Kafue scheme should be begun first. The latest information, he added, indicated that the potential power development of the Kafue scheme was greater than previously supposed, but that the capital cost was likely to be more than originally estimated. On the other hand, the cost of the Kariba development had probably been over-estimated, and it was also possible that the constructional period could be substantially reduced. In consequence the dates on which power would be available from either scheme might not be so very different. In view of these circumstances they had felt justified in having further expert opinion, and had asked Electricité de France to nominate two consultants, who had now begun to collect all relevant data.

Additions to Australian Plant

THE State Rivers and Water Supply Commission of Victoria has decided to increase the capacity of Eildon reservoir from 306,000 to 2,750,000 acre feet. This enlargement greatly exceeds the purely irrigational requirements for which the dam was primarily constructed, and will enable a further 120,000 kW of capacity to be added to the power plant. This power will be available for peak and emergency supplies in the winter months, when there is no demand for irrigation water. Two 60,000 kW turbo-generators have been ordered, and are to be installed in a new power station to be erected by the Utah Construction Company, who are also the contractors for the additional work on the dam. The two 7,500 kW units from the old power house will also be installed in this station. Balfour, Beatty & Co. Ltd. are the consulting engineers for this scheme, which is expected to be in production by 1956.

Further progress has been made with the Hume project, and the proposal of the River Murray Commission to increase the capacity of the reservoir from 1¼ to 2 million acre feet has now been adopted. The power station for this scheme will be located in New South Wales, and will be provided with two 25,000 kW sets. Sir Alexander Gibb and Partners are the consulting engineers.

Engineering Models and Apparatus

AT the Annual Conversazione of the Institution of Civil Engineers there was an exhibition of engineering models and many other items of interest. Of direct application to hydro-electric engineering was a series of experimental models, constructed of rubber, which were used in conjunction with the mathematical analysis of the stresses in an arched dam, with particular reference to that for the Lesser Zab River scheme in Iraq. These exhibits were presented by G. M. Binnie, M.A., M.I.C.E., of Messrs. Binnie, Deacon & Gourley, and Professor A. J. S. Pippard, M.B.E., D.Sc., Imperial College of Science and Technology.

The Dokan dam, now under construction on the Lesser Zab River, is 380 ft. high above the lowest foundation level and has a crest length of 1,150 ft. It forms part of what is primarily a large irrigation and flood-control project but provision has been made for a power station to be constructed, at a later date, at the toe of the structure. A glory-hole-type spillway has been arranged to discharge well downstream of the dam site.

Other models of dams, also cast in solid rubber, were designed further to demonstrate this new method which is now being used to evaluate stresses created by the water pressure. One of these was so arranged that the upstream section could be rapidly filled with water while a reflecting-type strain gauge indicated the amount of deflection on a scale in a very striking manner. Other models, also constructed in rubber by Rubber Developments Limited, represented sym-

metrical dams in a valley with vertical sides and in a vee-shaped valley. The use of these models not only saves a great deal of time but also affords a valuable check on the mathematical analysis of the stresses involved.

The Building Research Station, Department of Scientific and Industrial Research, exhibited examples of indicators used to measure displacements in structures. An extensive variety of gauges was shown, ranging from simple direct-reading instruments to elaborate remotely visual types, but all were designed to measure small movements such as might occur as the result of foundations settlement, shrinkage, temperature fluctuations and so on.

Spillimacheen River Development

THE British Columbia Power Commission now report that the 3,800 ft. tunnel which is being driven in connection with this scheme has been holed and will be lined to a finished diameter of 7 ft. Provision is made for a total installed capacity of 5,500 h.p. which will be distributed over three water-wheel generating sets. Two of these, each of 1,250 h.p., will be transferred from the now disused Barriere station while the third, of 3,000 h.p., will be supplied by the English Electric Company of Canada Limited. The turbines will operate on a head of 210 ft., of which 165 ft. will be provided by the pipeline. The total cost of the scheme is expected to approach $2·5 million, this figure including the 33 kV transmission line which will be put on load during 1955.

Scottish Progress

IN an address presented to the Aberdeen Rotary Club recently Mr. Thomas Lawrie, General Manager of the North of Scotland Hydro-Electric Board, stated that although the Board employed no more staff than it did in 1949, some 88,000 new consumers had been added to the mains, the production of electrical energy had increased by 200 per cent. and twelve new power stations had been commissioned. To meet the rapid growth of demand, he added, the construction of further water-power schemes was being planned and it was hoped that by 1959 the capacity of the Board's stations would be increased by 420 MW. The total capacity would then be over 819 MW, producing an output of 2,213 million kWh per annum, equivalent to a yearly coal consumption of one and a half million tons or the coal output of 5,000 miners.

Development Plan for St. John River

PLANS have been approved for the erection of a series of power stations on the St. John River, which flows partly through the State of Maine, U.S.A., and the Province of New Brunswick, Canada. These plans involve the development of ¾ million kW at an expenditure of some $200 million, and are estimated to take ten years to complete. Work is to begin on the first project, at Beechwood, New Brunswick, almost immediately, with the erection of a dam and power station which will have an initial capacity of 67,000 kW and an ultimate capacity of 100,000 kW. This site is 75 miles N.N.W. of Fredericton, the capital, and about 40 miles downstream of Grand Falls, where a private power company erected a power station over twenty years ago. The head available is 300 ft. The participation of the United States in these projects is due to the fact that the St. John River forms the international boundary between the two countries for part of its course, and some of the storage dams for regulation purposes will have to be erected in the United States.

ECE Power Committee

THE U.N. Economic Commission for Europe's Committee on Electric Power is now studying many economic, technical and legal problems connected with the development of European electricity resources to meet ever-growing demands for power. It will examine the electric power situation in Europe in the setting of post-war developments. Particular attention will be given to trends in production, consumption and international exchanges of electric power. Electricity supply installations put into service in 1953 and under construction will also be considered.

One of the principal and permanent aims of the E.C.E. Committee on Electric Power is to promote transfers of electricity between the different European countries. The importance of this work was again stressed by Governments during the recent annual session of the Economic Commission for Europe. The development of such transfers will make for the rational integration of Europe's electric power resources and for optimum efficiency in the operation of the different national grids. In this connection, the Committee at its present session is expected to give particular attention to possibilities for international action promoting the construction of electrical installations in various countries and their use for internal and international purposes.

Drave River Convention

AUSTRIA and Yugoslavia have now signed a formal Convention on matters of common interest concerning the use of the Drave River, whose waters flow successively through Austria and Yugoslavia. The Convention settles past differences on the use of the water of this river, and provides a regime for organising the flow of water from the Austrian hydro-electric central at Lavamünd to ensure supplies to Yugoslavia. For the future, the Convention creates a Permanent Mixed Commission for the exchange of information on the use and development of the river and for friendly settlement of differences.

The treaty was signed in connection with the current meeting of the Economic Commission for Europe's Committee on Electric Power. Representatives of countries from all parts of Europe witnessed the ceremony, which culminated discussions between representatives of the two countries begun in February 1952 under the auspices of the United Nations Economic Commission.

The Moriston Dam Scheme. Mitchell Engineering Limited have arranged with Newman Neame Limited to issue reports from time to time on contracts they have fulfilled. The first of these deals with the work they did in connection with the Cluanie development for the North of Scotland Hydro-Electric Board, and features the use of the Trief process (WATER POWER December 1953, p. 446). The report is excellently produced and well written from the technical viewpoint and fully illustrated.

Ours or Theirs?

The author discusses the problem of assessing the results of rain stimulation by artificial means, and describes methods that have been adopted to obtain a reasonably true assessment.

By WALLACE E. HOWELL

IN the spring of 1950, when the water supply of New York City was near exhaustion, religious leaders of many faiths called upon their followers to pray for rain, and the city entered upon an experimental programme of rainfall stimulation. Shortly thereafter, *The New Yorker* magazine ran a cartoon showing two young clerics peering through the rain-splashed panes of a vestry window, one asking the other, "I wonder if it's ours or theirs!" Despite the increasing acceptance of rainfall stimulation as an industrial procedure in the past four years, the question still rises in many minds whether it really works. The hesitance on the part of the government agencies and professional bodies to go beyond the most guarded statements has not helped to clarify the public mind.

When an extensive layer of stratiform cloud at a temperature below freezing is seeded with a nucleating agent such as dry ice or silver iodide, the effect is strikingly observable. The cloud along the path of the seeding is quickly converted to ice crystals, which snow out of a progressively widening band of altered cloud, leaving within half an hour or so a wide gap in the cloud layer. When the nuclei provided by the seeding are used up, the action ceases and the cleared band gradually becomes again filled with clouds and blends back with its surroundings. The effect is easy to observe in a manner that leaves no question that it is the direct result of the seeding.

However, seeding for stimulation of precipitation is generally done under weather conditions that approach or reach those producing natural precipitation, when complex and often unstable air motions prevail that confuse and may obscure the consequences of seeding which under more settled conditions are so singular. The question must then be asked whether the rain or snow would not have fallen just as copiously anyway, without the seeding. With regard to any single seeding event, that question is often very difficult to answer, even when elaborate observational techniques such as radar are used. Nevertheless, it is not out of the question to seek for the cumulative effects that would be expected to accrue during a long series of cloud seedings until they become discernible against the background of chance variations.

Beginning at the time of the first large-scale experiments in precipitation stimulation, studies have been made of individual seeded weather situations. Startling indications of widespread influence were found, but there was always the nagging doubt whether the indications might not be illusory. More and more, as experience has accumulated, attention has turned toward objective analysis of accumulated results and statistical testing of their significance.

Rainfall from Individual Seeding Occasions

The most primitive step in investigating the consequences of an individual seeding occasion is to map the precipitation at all available observing points and consider its distribution in relation to the position of the source of artificial nuclei and the direction of their drift with the wind. Fig. 1 is an example of such a map. The circled "S" marks the position of a silver iodide smoke generator, and the arrows show the mean trajectory of the smoke over a time interval of one hour. Such a map contains all the extraneous effects such as the differing exposure of the several precipitation gauges, the influence of terrain on the precipitation, and so on. It gives no information as to whether the precipitation amounts or the pattern

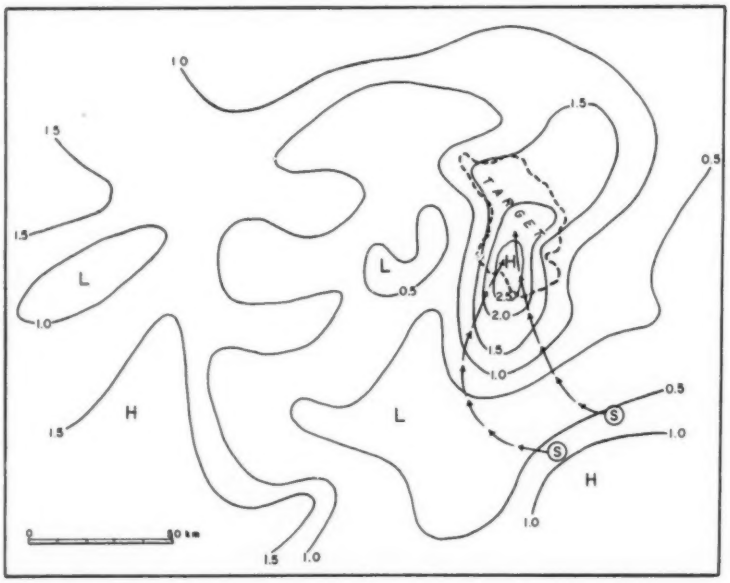


Fig. 1. Inches of rainfall produced by a seeded storm; the circles indicated S *show the location of the generators at different periods of seeding during the storm and the arrows point the approximate trajectory of the smoke during a period of one hour*

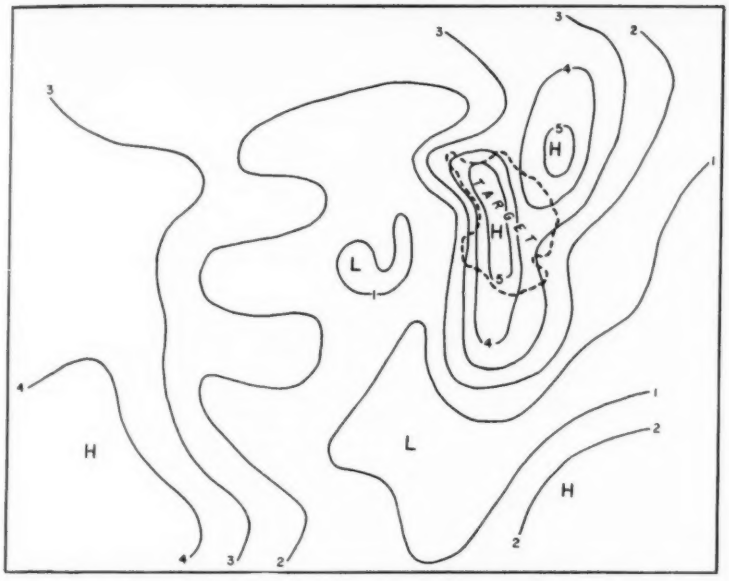


Fig. 2. Rainfall produced by the same storm as in Fig. 1, expressed as percentages of the normal annual rainfall

of their distribution are at all unusual.

Refining the description one step further, the precipitation at each gauge may be expressed as a percentage of the normal for the appropriate month of the year. Fig. 2 shows the same occasion as Fig. 1, with the amounts expressed as percentages of the 13-year annual normals at all stations for which such normals are available. The effects of exposure and orographic influence are largely compensated, but no information is yet given as to whether the amounts or the patterns are unusual.

A further refinement is achieved by expressing the precipitation at each station by the rank that it occupies in an ordinal listing of all amounts observed from individual storms at that station over a long period of time. The numbers on the map, Fig. 3, indicate, for the same occasions as before, the rank standings of the precipitation amounts, each with reference to amounts recorded in previous storms at the same gauge arranged in descending order of magnitude, based on thirteen years of record covering approximately 1,500 storms. Hence the numbers correspond to the number of times that the precipitation of this particular storm has been exceeded in other storms during the thirteen-year period. Disregarding small irregularities, it is just as likely that the precipitation at some gauge in the storm under investigation will occupy a given place in the rank list as that it will occupy any other particular place; and since each amount is compared with the past record of the same gauge, factors of gauge exposure and orography are compensated. This form of presentation thus gives useful information about the likelihood of occurrence of the amounts as well as a picture of distribution unbiased by local influences.

From Fig. 3, it seems likely that the region of heavy rainfall lying near the end of the arrow resulted from the seeding. The likelihood seems even stronger when a sequence of similar maps is studied. Fig. 4 is a composite map showing for a series of seeded storms the locations of the nuclei generators, the wind directions, and the locations of most outstanding precipitation. Nevertheless, no matter how strong the impression becomes, no basis is afforded for an objective expression of the confidence to be placed in the conclusion that cloud seeding is responsible for the observed distribution of precipitation.

A number of other methods for studying seeded storms have been tried, of which a few should be mentioned. There is, of course, a relationship between the quantity of precipitation and the concomitant physical state of the atmosphere; there cannot be heavy rain without an adequate supply of moist air and a suitable system of converging winds. If sufficient information can be assembled and analysed to permit making an accurate forecast of the amount of natural precipitation to be expected in connection with a given physical state of the weather, then comparison of the

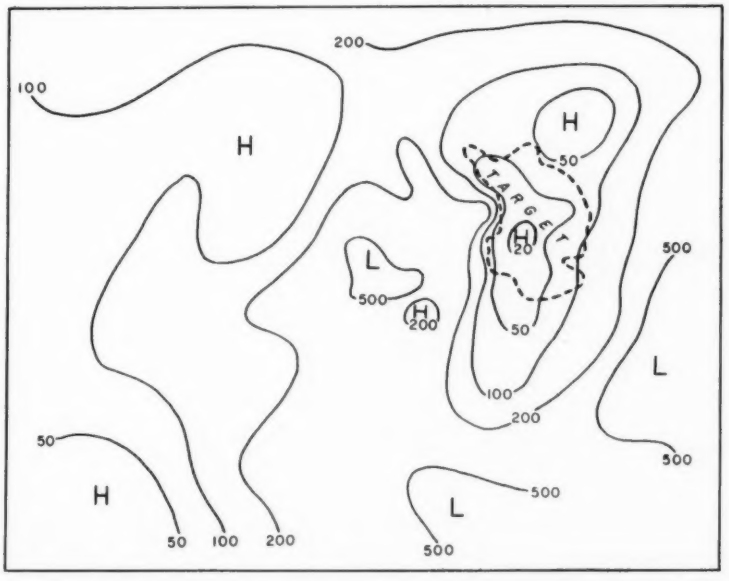


Fig. 3. The rainfall of the storm, Fig. 1, expressed according to the rank standing of the rainfall amount in a series of 13 years

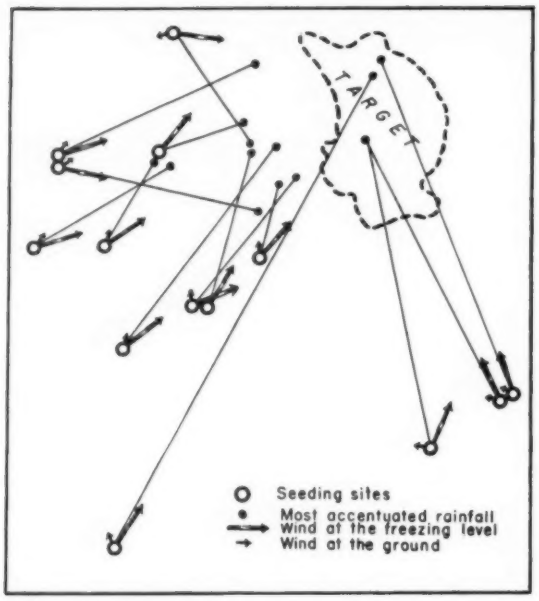


Fig. 4. Sites of seeding and the positions of the most accentuated rainfall from a series of seeded storms for a single target area

forecast rainfall with the observed rainfall after seeding would reveal the degree of stimulation. Unfortunately, a sufficiently complete analytical description of the weather is not yet possible, and quantitative forecasts of precipitation are notoriously inaccurate.

It is at least reasonable to assume that a given storm will perform in the same way as another exactly similar storm, occurring in the same place and at the same season of the year, would perform. Old weather maps may be searched to find past storms as nearly similar as possible, in their antecedents and the pattern of their development, to the seeded storm up to the time it was seeded, and then the subsequent behaviour of the seeded storm may be compared with that of its past parallels. The search of the past is materially aided by two devices, one a catalogue of more than forty years of daily weather maps encoded on punched cards according to the magnitude and location of pressure centres, and the other a similar catalogue of the same maps encoded according to the location and behaviour of certain large sub-tropical high-pressure cells that are thought to be closely related to the large-scale behaviour patterns in the atmosphere. By means of these catalogues it is possible to consult several past maps that resemble more or less nearly the weather situation just prior to seeding and to compare their subsequent developments. This approach to the problem is essentially a systematisation of the experience principle and a synthesis of many varied physical parameters into broad characteristics of the weather situations. It has not yet been perfected to the state where the degree of confidence to be placed in the indicated results can be expressed.

Objective Analysis of Accumulated Results

Since the purpose of stimulation is to increase the precipitation, the simplest thing to look for is evidence that the precipitation on the target was heavier while seeding was going on. But, one asks, heavier than what? That's the rub.

During the summer of 1953, for example, cloud seeding was done for five periods of two weeks each, the target being the cane lands of a sugar mill near Guantanamo, Cuba. Fig. 5 shows the rainfall during this succession of two-week periods and the corresponding rainfall for previous years, averaged over ten rain gauges in the plantation area. The solid horizontal line represents the mean rainfall of the unseeded years, and the dashed lines are separated from the mean by the "standard error" of the datum points, a measure of their scatter about the mean. It is immediately clear that there is nothing sufficiently unusual about the 1953 rainfall for any conclusion to be reached regarding the effectiveness of the cloud seeding.

If the experiment were repeated a number of times, the mean of the seeded years might eventually show a significant change from the mean of the previous years. But a meteorological mean is at best a rather inconvenient fiction, for the weather undergoes cyclic and secular changes so erratic that the mean from one epoch cannot be assumed to apply to any other epoch. It would be necessary to seed on alternate years, or better still on randomly selected years, and compare the mean rainfall of these years with that of the unseeded years in between. Such a procedure would

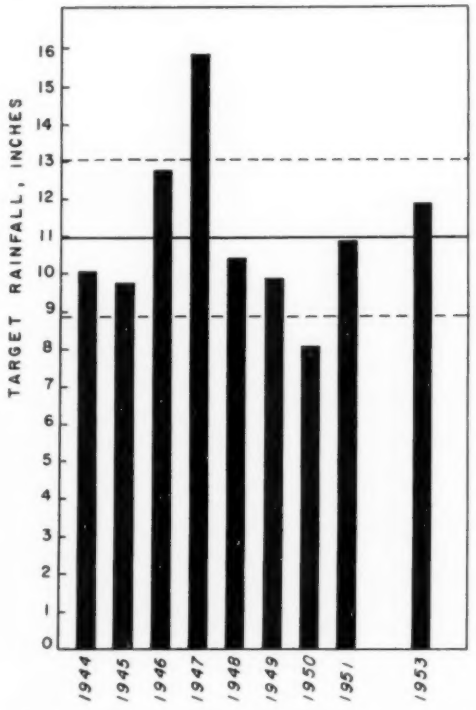


Fig. 5. Rainfall during unseeded years, 1944 to 1951, and during the seeded year 1953 on a target area near Guantanamo Bay. The year 1952 is omitted because of seeding nearby that may have influenced the target. The firm horizontal line represents the mean and the two broken lines are separated from it by one standard deviation

be expensive of time and treasure. Fortunately, however, it can be improved upon.

In the vicinity of Guantanamo there are a number of sugar plantations near the target area that have a similar rainfall regime, and these plantations may be utilised as a control area. The degree of similarity is shown, in Fig. 6, by plotting the rainfall of the target against the mean rainfall averaged from 54 rain gauges in the surrounding plantations for the portions of previous years that correspond to the 1953 seeding periods. The solid line is the regression line expressing

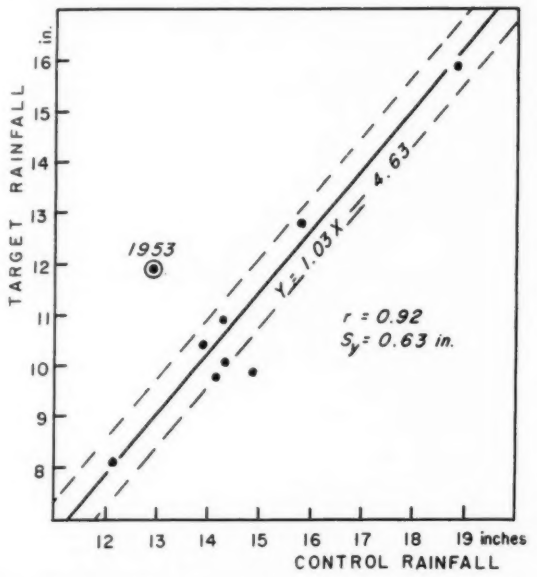


Fig. 6. Rainfall on a target near Guantanamo Bay as related to rainfall on a nearby control area (Fig. 8). The heavy line represents the mean regression and the broken lines represent one standard deviation on either side

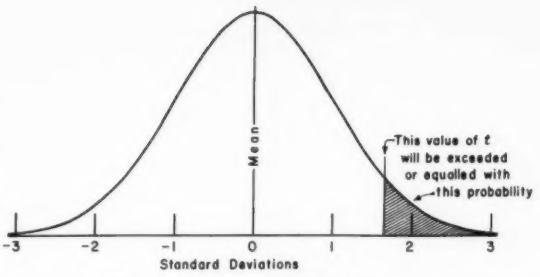


Fig. 7. The probability function

the mean target-control relationship, fitted according to the method of least squares. The correlation coefficient r expresses the degree of target-control similarity, and the dashed lines show the "standard error" of the target-control regression. In 1953, the control region suffered low rainfall, and past experience leads to the confident expectation that the target rainfall should also have been low. In actuality, the 1953 rainfall on the target exceeded the expected amount by about four times the standard error of the regression.

The likelihood of this event occurring by chance may be determined in the following manner. It is first assumed that the departures of the historical data points from the regression line follow the normal error distribution illustrated by the bell-shaped curve in Fig. 7. The assumption is tested, and if it is found untenable the data are transformed (see later discussion) in a manner to make them conform to the normal distribution within allowable limits. The likelihood that the departure to be tested would be equalled or exceeded by a single chance occurrence of the class of events being tested is then represented by the shaded area under the right-hand end of the curve expressed as a fraction of the total area under the curve, and this likelihood is called the *probability* that the departure will equal or exceed t. This procedure is known as a t-test, and the probability values are

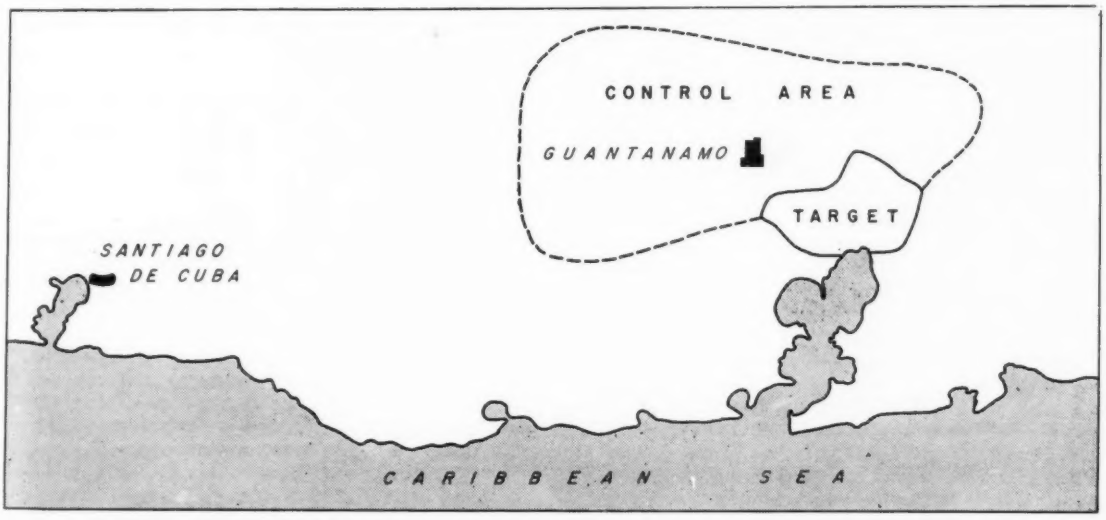


Fig. 8. Target area near Guantanamo Bay, Cuba, showing control area used in evaluating the rainfall relationships

tabulated in statistical handbooks in such a manner that due allowance can be made for the uncertainty of fit of the normal curve when historical data are scanty.

In usual statistical practice, if the probability of the event t is greater than 0·05, it is not considered to be significantly different from the historical data. If the probability of chance occurrence is 0·05 or less, the occurrence is considered to be significantly different from the historical data (often spoken of as "significance at the five-per-cent. level"), although for certain situations where the penalty for a wrong judgement is severe, as for example the testing of a new drug that might be harmful, a probability of 0·01 may be used as the criterion of significance. In dealing with precipitation it is probably wise to use the more conservative one-per-cent. criterion because of secular climatic changes that might conceivably cause unusual target-control differences to occur somewhat more frequently than predicted by classical statistics.

Applying the t-test to the data of Fig. 6, it is found that the excess of 1953 rainfall on the target over the quantity expected would be equalled or exceeded by chance with a probability less than 0·001; that is, it would be expected to occur by chance in fewer than one trial out of a thousand. It can therefore be stated with a very high degree of confidence that the increase is due to the cloud seeding rather than to chance.

It is worth noting from the map of the target and control areas, Fig. 8, that parts of the control area may have been and very probably were influenced by the seeding, tending to boost the "control" rainfall and conceal a portion of the actual increase on the target. This disadvantage must be weighed against the still greater disadvantage of the poorer correlation that would result if a more distant control area, farther from possible influence of the seeding, were selected. The procedure illustrated yields a sensitive but conservative test of the efficacy of the cloud seeding.

When the target area comprises a watershed, comparison of the run-offs from the target and from nearby watersheds used as controls provides an alternative method of analysing the effectiveness of precipitation stimulation procedures. The run-off analysis uses an entirely separate set of data, subject to different errors and disturbances, related to the precipitation data only through the physical actuality of the rain and snow as a source of run-off. Especially in mountainous terrain, an observation at a particular gauge site is likely to be unrepresentative of the surrounding precipitation, whereas the run-off integrates orographic precipitation differences. Where good run-off records are available, analysis of them may provide a more accurate and sensitive test of cloud-seeding results than can be obtained from the precipitation data, especially if the latter are inadequate.

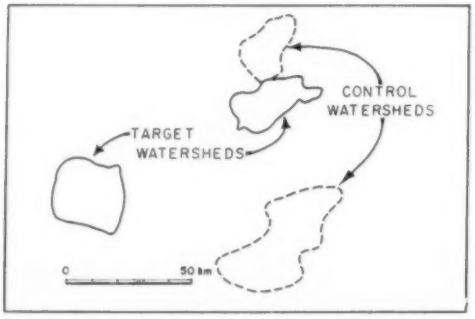


Fig. 9. Target and control watersheds used in a runoff evaluation of cloud seeding in north-eastern United States

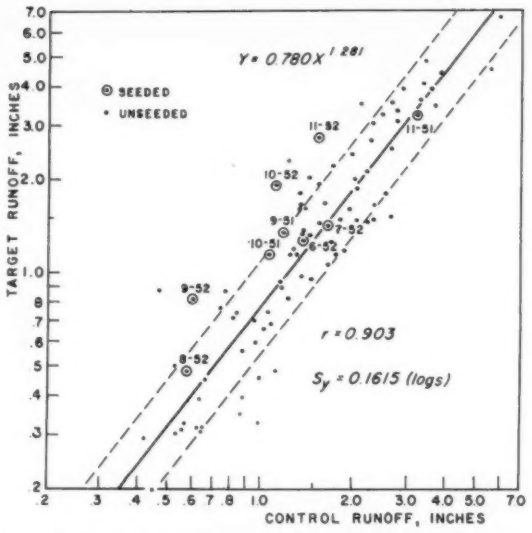


Fig. 10. Correlation diagram of runoffs from the target and control areas used in evaluating a cloud-seeding programme

After seeding had been done for nine months, three in 1951 and six in 1952, for two hydro-electric watersheds in the north-eastern United States, the hydro-electric company selected the two watersheds shown on the map, Fig. 9, for a run-off comparison. Fig. 10 is a correlation diagram comparing the target and control run-offs during the seeded months with those of the same months during previous years of record. In this instance it became necessary to take cognisance of the skewness of the natural run-off distribution (the fact that deficits are both smaller and more frequent than excesses), for the standard statistical measures of probability do not apply if the data fail to conform reasonably well to the normal error distribution. In Fig. 10, the common practice of transforming the run-off values to the logarithm of these values has been followed. A cube-root transformation is also useful in treating with skew distributions of precipitation data. It should be remarked that these transformations do not compromise the generality of the tests, since they in no way affect the fundamental relationship between the variables.

In Fig. 10, as in the preceding ones, the solid line is the regression line and the dashed lines delimit one standard error to either side of it.

Very few of the seeded months show deviations of run-off that by themselves appear at all remarkable. Nevertheless the intuitive impression is gained that enough of these points are far enough from the regression line so that the set as a whole may have some claim to significance. The problem is to apply a test of significance that combines the several deviations into a single expression of the probability of their joint occurrence. Several methods have been devised for applying such a test, and are summarised in a

forthcoming publication by Boucher.* Perhaps the best adapted to the purpose at hand is that proposed by Stouffer, who noted that the sum of the deviations of a normally distributed variate with unit variance is itself a normal variate with variance equal to the number of deviations summed. The combined deviation that becomes the subject for a new t-test is therefore the sum of the individual t values divided by the square root of the variance, that is, the square root of the number of individual t values. The probability of the new t value being equalled or exceeded by chance is then found from standard tables in the usual way.

The 1951 data presented in Fig. 10 indicate a mean stimulation of only 9·5 per cent. above the amount predicted by the regression line. Application of the Stouffer test yields a probability of 0·185 (one in 5·4) that the joint deviation may be due to chance. This is not a significant result. For the year 1952, however, the run-off was 53 per cent. above expectation, and the Stouffer test gives the very significant result that the probability of chance occurrence of such a combination of deviations is only 0·003.

It so happens that the seeding programme in 1951 had been based upon operation of the cloud-seeding generators by personnel of the sponsoring company whose primary duties lay elsewhere, and as a consequence operating instructions had not been well carried out and equipment had not been adequately maintained, the efficacy of the programme suffering acutely from these derelictions. In 1952, however, all operations had been the direct responsibility of the meteorological firm, and efficient operation was maintained. The results of the analysis are therefore entirely consistent in indicating poor results in the first year and good results in the subsequent year. If the outcome had been reversed, doubt would have been cast on the results.

The technique of combining the results of several significance tests into one test of the overall significance offers a means of answering the question whether precipitation stimulation as a whole has attained significant results, and if so, how significant. In performing such a test it is obvious that there should be no subjectivity in the selection of the data so as to show unduly favourable results. Table I lists all the projects undertaken by a particular precipitation stimulation firm which it has been possible to subject to statistical analysis of the type described above, without regard to the individual results. The only projects omitted were those for which historical data were missing or the operating period was too short for an analysis to be performed.

In Table I are listed the individual t values for each operating period, adjusted according to Student's theorem for the size of the sample, together with the duration of the period in months and the corresponding probability of chance occurrence. At the bottom of the table, the t value for the entire group is listed, with the corresponding probability. It shows that the likelihood that the overall results have been due to chance rather than to stimulation by seeding is less than one in a hundred million. This is indeed an impressive result. It may safely be regarded as conclusive proof of the effectiveness of cloud seeding for precipitation stimulation. Any successful challenge would have to be brought on some broad fundamental basis. A challenge against one or even several of the individual tests could not seriously affect the conclusiveness of this proof.

Smaller groups may likewise be tested for special purposes. For example, the sub-totals in Table I show the results of the combined test applied to the low-elevation tropics (Cuba), the high-elevation tropics (Peru), and middle-latitude areas, while the sub-totals at the foot of the table show a combined test of the significance of rainfall evaluations separately from run-off evaluations. Each of the area groups independently shows a probability of chance occurrence less than two in a thousand. However, the tests are incapable of indicating whether precipitation stimulation is more effective in one climate than in another, or more effective for precipitation than for run-off, for the calculations of probability are influenced heavily by the quality of the data and the adequacy of past records as well as by the effectiveness of the cloud-seeding operations.

A word is in order regarding the independence of any one of the operating periods listed in Table I from the others, for unless the data represent independent events the result of the combined significance test will be false. The critical datum for each operating period tabulated is the difference between the observed rain-

* Boucher, R. J., "A Statistical Evaluation of the Significance of Commercial Cloud Seeding by Means of Combined Tests."

TABLE I. SUMMARY OF STATISTICAL RESULTS OF PRECIPITATION STIMULATION PROJECTS

Region	Data	Duration Months	Deviation t	Probability of t being equalled or exceeded by chance
Cuba	Rainfall	4	3·00	0·001
Cuba	Rainfall	3	1·79	0·04
Cuba	Rainfall	7	1·20	0·12
Cuba	Sub-total	14	3·28	0·00053
Peru	Rainfall	1	1·80	0·04
Peru	Rainfall	1	1·36	0·09
Peru	Rainfall	1	0·05	0·48
Peru	Rainfall	1	0·17	0·43
Peru	Rainfall	1	0·80	0·21
Peru	Rainfall	1	1·28	0·10
Peru	Rainfall	1	2·18	0·01
Peru	Rainfall	1	1·07	0·14
Peru	Sub-total	8	3·08	0·0014
New England	Rainfall	2	1·75	0·042
New York	Run-off	1	0·86	0·19
New York	Run-off	1	0·83	0·20
New York	Run-off	1	−0·02	0·51
New York	Run-off	1	0·29	0·39
New York	Run-off	1	0·68	0·25
New York	Run-off	1	−0·11	0·54
New York	Run-off	1	1·89	0·03
New York	Run-off	1	1·93	0·03
New York	Run-off	1	2·05	0·02
Quebec	Run-off	1	0·92	0·18
Quebec	Run-off	1	1·09	0·14
Quebec	Run-off	1	0·97	0·17
Quebec	Run-off	1	1·32	0·10
Quebec	Run-off	1	−0·54	0·71
North-east North America	All	16	3·67	0·00012
All	Rainfall	24	4·64	0·000010
All	Run-off	14	3·25	0·00080
All	All	38	5·65	$8·7 \times 10^{-9}$

fall in the target area and a single-valued function of the observed rainfall in the nearby control area. Two questions must be asked: Is this datum for one month independent of the same datum for the same target and control areas for the preceding or following month? And is it independent of the same datum for a different target and control area for the same month? It is well known that large-scale weather patterns show a certain degree of persistence from month to month, so that if the target rainfall is abnormal in a given month it is somewhat more likely than not that abnormality in the same direction will be found in a preceding or following month. However, the nearness of the control areas to their respective targets, so that both are under the same large-scale influences, and the correlations observed between target and control rainfalls both argue strongly against the critical datum exhibiting any month-to-month persistence based on large-scale weather persistences.

It seems likely that only by the greatest skill and good fortune could two target-control pairs be selected such that the critical datum for each would be influenced in the same manner in a given month. If the targets tended to lie mostly in one climatic regime and the controls mostly in another, there would be some grounds for question. As it is, target areas are determined principally by economic considerations and they are situated in a wide variety of climatic regimes, with the control regions resembling their respective targets much more closely than they resemble one another. Therefore there appears to be no basis for an assumption of dependence of the critical datum of one project on that of another.

Indicated Magnitude of Stimulation

Let us turn now to the question of how large a degree of stimulation is achieved. Table II shows the distribution of percentage increases in rainfall and run-off.

The first striking characteristic of this distribution is that it is much broader than one would expect if the meteorological potential for stimulation were constant and the distribution of percentages arose only from experimental errors in determination of the actual percentages. In other words, the distribution shows first of all that the degree of stimulation achieved by commercial cloud-seeding operations depends greatly upon climatic and weather factors that vary widely from place to place and from epoch to epoch. Procedures that meet with spectacular success in one instance may upon another occasion yield disappointing results or even appear to have diminished the precipitation. Herein lies a physical basis for the lack of correspondence between the results reported by different investigators. It is worth mentioning that the three highest and the three lowest percentages included in this tabulation derived from work carried out in north-eastern North America, a region of notably high variability of the important meteorological elements.

There are several ways of expressing the central tendency of the percentage values. The mean of 35 per cent. and median of 25 per cent. illustrate the skewness of the distribution. If one sums up the actual inches of rainfall and run-off increase and expresses it as a percentage increase over the expected sum, the average increase is found to be 26 per cent. Comparison of this average with the mean of the percentage figures shows that, on the whole, the larger percentage increases must have been associated with the smaller rainfalls. This association suggests that cloud seeding is less effective under weather conditions that lead to high natural precipitation than under low-precipitation conditions. It is possible that the high-precipitation epochs tend to coincide with epochs when natural precipitation-initiating mechanisms in the atmosphere are especially competent, whether from the presence of large numbers of natural ice-forming nuclei or for other reasons, while the epochs of low precipitation tend to correspond with epochs when natural nuclei are deficient and the natural precipitation-initiating mechanisms are handicapped and hence cloud seeding could appear at its best.

Discussion

If such conclusive evidence can be presented in support of the effectiveness of cloud seeding for rainfall stimulation, why should there be such widespread doubt, even in scientific and official circles, in regard to this effectiveness? The answer is somewhat complex.

In the first place, commercial rainfall stimulators have been limited in making known the exact results of their operations by the interests of their clients in avoiding possible legal complications, and up to the present time the literature on the subject has not contained any comprehensive technical review of a large number of projects. Even the data presented in the preceding section of this article have been only recently presented at scientific meetings and have not yet (as of March 1954) appeared in print.

But the doubts entertained by many qualified meteorologists are rooted more deeply and cannot be explained away simply as a "cultural lag." To understand the matter more fully one must appreciate that the field of rainfall stimulation lies on the frontiers of scientific knowledge where scientists are still groping to uncover new facts and then to organise them into useful patterns of knowledge. To quote from the recent book by Donald Menzel of Harvard University on flying saucers:—

"A layman, watching a group of scientists arguing about some technical question, may gain the impression that the disagreement between them is serious. If he could check the argument in detail, however, he would find that the scientists are usually in almost complete agreement about the basic facts and that the arguments usually concern matters on the fringes of human knowledge."

In this instance the area of basic facts where agreement exists embraces nearly all of what is known about the composition of clouds and their structure and form, the air motions that give rise to them, the cyclonic and anticyclonic systems into which these motions are organised, in a broad way the part played by water and water vapour in the large-scale transfers

TABLE II. FREQUENCY DISTRIBUTION OF PERCENTAGES OF RAINFALL AND RUN-OFF INCREASE

Per cent.	−20-0	1-20	21-40	41-60	61-80	81-100	101-120
Rainfall -	0	5	9	6	1	2	0
Run-off -	3	2	6	1	0	1	2
All cases -	3	7	15	7	1	3	2

of heat from one part of the atmosphere to another, etc. It also embraces the facts that have been reported from the laboratory regarding the efficacy of various seeding agents in supercooled clouds under laboratory conditions and under certain atmospheric conditions, as described earlier, where the outcome is strikingly obvious. These may be thought of as primary changes in cloud composition produced by seeding. The fringe area, where disagreement exists, concerns the efficacy of certain seeding techniques, and the secondary consequences of the changes induced in cloud composition on the development of the clouds, release of energy within them, on the structure of the clouds and cloud systems, and even on the structure of atmospheric disturbances as a whole—changes that are difficult to observe and evaluate with certainty.

It is within this fringe area that research is actively going forward, research that has been greatly stimulated by the attention attracted by the practical aspects of precipitation stimulation. Disagreement and controversy in this area are healthy signs, for they arise from the energetic search for new light and the active exchange of ideas. Intriguing new facts are suggestive of a host of theoretical speculations which quite naturally generate disagreements. One can take encouragement from the assurance that eventually the new theories will be modified and refined to the point where they will become dependable explanations of the facts that are now so puzzling, and the fringe area will move onward.

Theoretical speculations at the present time align themselves with one of two principal schools of thought that dominate most current meteorological research. One of these, originating early in the present century with the fruitful application of hydrodynamic and thermodynamic concepts to the atmosphere, has dominated the field for several decades to the point where it now occupies the position of a classical school. It has been outstandingly successful in developing our understanding of the behaviour of atmospheric disturbances and the part that they play in the response of the atmosphere to its large-scale driving forces. The theories at present developing within this school as they apply to precipitation stimulation regard the consequences of atmospheric perturbations as being convergent in nature. They contend that the alterations of natural conditions produced by cloud seeding cannot be other than local and ephemeral, and that they are soon lost in the interplay of far more powerful forces. The outlook of the school might be compared to the doctrine of predestination in the field of philosophy—that meteorological events will continue to march forward with majestic indifference to man, each day's weather completely predetermined by antecedent conditions. Estimates that precipitation might be locally increased by a few per cent., but certainly not by more than four or five per cent., are typical of the outcome of this theoretical approach.

The other school of meteorological thought, much younger and less firmly established, is more akin to the philosophical doctrine of free will. It accords a more important place to the factors of chance, especially in regard to the time and place of origin of new atmospheric disturbances. These disturbances are known to grow during their early stages in an unstable manner by conversion of potential into kinetic energy. The rebels of this school argue that relatively small releases of energy or inhibitions of release can, by determining at a critical time when and where young disturbances will get started, exert an influence quite out of proportion to their magnitude. The theories put forth by this school envisage the atmosphere as far more labile and less predictable than has heretofore been thought. It is as if, in various key locations, free choices were continually being made as to what the weather would do next, even though it is conceded that the overall consequences of these choices must be bound by the laws of energy supply and demand within the atmosphere. It is possible, reason the proponents of this school, that cloud seeding may start a chain of events that will result in every substantial increases in precipitation. The point of view has been very dramatically stated by Dr. Irving Langmuir in his suggestion that it is easier to control the weather at Buffalo, N.Y., than it is to predict it.

It is likely that the state of ferment in the theoretical approach to precipitation stimulation will continue for a considerable time, since the factual basis is still far from adequate for a complete and explicit knowledge of all that goes on when the clouds are seeded. In the meantime, it is possible to overleap the bramble-patch of theory even while the work of untangling it is going on, by a pragmatic approach. Regardless of the arguments over theory, let us give precipitation stimulation a practical try-out and see if we can obtain workable answers to the question whether stimulation is a practical possibility. After all, atomic energy has been put to practical use even though theoretical understanding of the binding forces within the atomic nucleus is still incomplete. If the practice of precipitation stimulation stands up to the tests of experience and proves to be useful and valuable, one may not only be sure that theoretical interest will be further stimulated but also that the facts determined from experience will prove invaluable in advancing the theoretical knowledge. It is in this spirit that the analysis in the foregoing section has been presented.

Orders for Small Turbines. Recent orders received by Gilbert Gilkes & Gordon Limited, Kendal, include one from the Philippine Islands for a propeller turbine developing 330 h.p. on a head of 23 feet, and directly coupled to a vertical-shaft alternator, which is to be manufactured in the U.S.A.

Other orders include two vertical-shaft Francis turbines each developing 1100 h.p. on a head of 22 ft. for the Potaro Hydro-Electric Co. Ltd., of British Guiana, and two Turgo impulse wheels each developing 3135 h.p. on a head of 590 ft. for Kilembe Mines Limited in Uganda.

Power Transformers. Publication No. 51103 issued by The Brush Electrical Engineering Co. Ltd., of Loughborough, illustrates and describes this firm's transformers ranging in size between 2,000 and 45,000 kVA. The various sections deal with the thermal, mechanical and electrical aspects of the Brush design and the facilities which the company possess for research.

Owen Falls. In the list of contractors published as an addendum to our article on this scheme it should have been stated that the concrete mixing and batching plant was supplied by Winget Limited.

The International Conference on Large Electrical Systems (CIGRE) 1954

A review is given of those parts of the proceedings of the Conference which are of special interest to hydro-electric engineers.

THERE are two great international forums concerned with electrical engineering—the World Power Conference and the International Conference on Large Electric Systems (CIGRE)—but hydro-electric engineers are only interested in about half of the subjects which come under discussion. They are only remotely concerned with the operation of thermal plant, and in regard to the CIGRE proceedings, which have been described as starting at the coupling between the prime mover and the alternator, they are not so much concerned in the details, for example, of the design of transformers and switchgear, but rather with the broader principles of the transmission of the power they generate so elegantly, without using any irreplaceable fuel.

Alternators

There is, however, one item of electrical plant with which they are intimately concerned—the alternator; and at the 1954 CIGRE Conference held, as usual, every second year in Paris, there were a number of aspects of the alternator papers and discussions which are of special interest to water-power engineers.

First, we may touch on the interesting paper presented by Ing. J. Tittel, of Siemens Schuckertwerke of Berlin. The paper dealt with the probable future need for variable-speed synchronous machines for stations in which there is a considerable variation in head, and where it is necessary that the alternator should function at two different speeds in order to obtain high turbine efficiency, or for pumped storage stations where a higher speed is required for pump operation than when operating as an alternator.

The paper indicated that the method of pole changing or pole-commutation, as the author called it, was successfully applied to two 19,600 kVA machines designed during the war years, but owing to the hostilities, never put into commission. Since the war, the author's company have been experimenting with a 450 kVA test machine, provided with arrangements for pole-commutation in the ratio of 9 to 11, so that it can operate on a 50 cycle system at 333 r.p.m. and 273 r.p.m.

This machine has been fully tested and it was seen that with the exception of three extra connections and connecting strips for short-circuiting four poles, the rotor was of standard construction, with salient poles and a damping winding. The pole-commutation in the rotor was achieved by means of the connecting terminals in such a way that the number of collecting rings was not increased. The tests showed that the ion losses with this arrangement were 16 per cent. greater than normal, but this figure was not considered as being particularly significant. No increase in temperature rise of the machine was noticed when it had been changed from one connection to the other.

Finally, the author suggested that for ratios of poles ranging from 0·9 to 0·75, it is now possible to obtain by this commutation method an efficiency of up to 75 per cent. with a normal type of alternator where the same power is required at both speeds.

An interesting paper by Messrs. R. David and L. Gatesoupe of Le Matériel Électrique S-W and Alsthom respectively, dealt with the problems of high-speed excitation and de-excitation of alternators used in hydro-electric stations. The French electricity supply authorities have recently put into commission two types of new excitation control, one known as the spontaneous impulse type, the other being the type in which the amplidyne and the electronic voltage regulator are used.

The first system, the spontaneous impulse system, works as follows. A sudden variation in the rotor current due to the effect of a disturbance in the network produces a transient current in the secondary winding of a transformer with an air-gap core. This transient current is used to excite an auxiliary machine called an impulse exciter, which is driven by an auxiliary motor whose armature is connected as a boost-and-buck circuit in series with the field of the main exciter. The flux of the impulse exciter is established instantaneously, as the linkage established by the air-gap transformer enables it to be derived from the flux of the alternator itself. As a result, this device exerts an instantaneous action upon the variation of the main exciter flux, thus increasing the rapidity of the correction of the alternator flux.

The second system in which an amplidyne and an electronic voltage regulator are used has several variations, but for a large-output low-speed hydro-electric alternator, the main exciter on the shaft of the generator itself takes the form of a constant-voltage generator, while a boost-buck exciter with a high rate of response and a high voltage ceiling driven by a direct-current motor fed from the main exciter, is arranged in series with this exciter and the main generator field winding. The amplidyne, which supplies the field winding of the boost-buck exciter, has two fields, one fed from the constant-voltage main exciter and the other from the voltage regulator. This regulator is of the electronic type and includes a measuring system made up of a Wheatstone bridge with a linear resistance and a non-linear resistance, while the current flowing in the amplidyne control field circuit passes through four standard Post Office long-life triodes, connected in push-pull. The voltage produced by the bridge arrangement and applied to the grid of the valves is a function of the difference between the voltage of the alternator and the regulated value determined by a setting rheostat which forms one of the arms of the bridge.

The authors showed that either of these devices

could be successfully used to limit surges in the case of sudden loss of load, or to reinforce very rapidly the rotor flux when an external short circuit occurs in the network.

They also mentioned that it was desirable that alternator engineers should evolve a generalised definition for the relative rate of response on load of different excitation devices, so that the results obtained on devices of different characteristics could be properly compared.

The problems of stator insulation appear to have been rather more seriously considered in North America and in one or two Continental countries, than in the rest of the hydro-electric world. A paper on this subject was presented by Mr. W. R. Way, of the Shawinigan Water and Power Company, of Montreal, and among the conclusions reached was that the incidence of stator faults increases markedly with operating temperature. The author suggested that improved means should be developed to give a continuous and accurate indication of actual conductor temperature, while there was general agreement in the discussion that the present specifications governing the heating of stator insulation will have to be revised in view of past experience. There was also the need for a reliable criterion for the appraisal of the physical state of the insulation on any particular installation, and this appraisal should be obtainable by non-destructive methods. In this connection a paper presented by Messrs. Graham Lee Moses and John C. Botts, of the Westinghouse Electric Corporation, U.S.A., was of special interest, since it dealt with a new type of insulation for stator windings which appears to offer the promise of meeting all the objections to previous methods. This process, known as the Thermalastic process, has the advantage of providing a continuous insulation extending from end to end of the coil while it has the necessary resilience to allow the movement caused by the relative expansion of copper and iron to be compensated for, the insulation returning to its original position once the temperature cycle has been completed.

The "secret" of this new type of insulation lies in the use of a specially developed impregnant to be applied to the mica tape. This impregnant is a synthetic resin, which is a copolymer solution of a linear polyester and a monomeric solvent. Due to the low viscosity of the impregnant, which is much lower than any previously employed, it can be completely impregnated into the interstices of the mica type insulation. The particularly important feature of the new type of insulation is that once the stator coils have been impregnated, the resin is completely polymerised to form a cross-linked thermoset solid. The voids and liquid inclusions which have given trouble in previous types of insulation are claimed to be completely avoided in this way, since all the resin present is completely reacted. The new insulation has excellent electrical and mechanical properties, and is also highly resistant to moisture. Its disadvantages are that the completed coils require special control of shape during manufacture and a modified technique during winding.

This paper was received with considerable interest and there was a general feeling that the new insulation would have important applications, although some manufacturing engineers felt that other lines of research, directed towards the improvement of methods at present used and employing materials of the highest grade, might well be developed to rival the Thermalastic principle.

The Russian delegation to CIGRE presented a paper giving one or two of the rare glances of what is happening in hydro-electric development behind the Iron Curtain. Their paper was entitled "Large Hydro-electric Generators of the Soviet Union," and stated that at the present time units with a capacity of 123·5 MVA and a speed of 68·2 r.p.m. are being constructed for stations on the Volga River, while even larger units, with a capacity of 200 MVA, are being designed for hydro-electric projects on the Siberian rivers.

A table given in the paper showed some of the leading characteristics of typical large units at present under construction.

Capacity kVA	Speed r.p.m.	kVA per r.p.m.	Outside diameter of frame, mm.	Load on thrust bearing, tons
68,750	62·5	1,130	14,400	2,100
103,500	83·3	1,080	13,100	1,000
71,500	62·5	1,140	15,500	2,000
123,500	62·2	1,820	17,400	3,400

The authors stated that the synchronous reactance and the transient reactance of their large machines had to be lowered (to 0·51 and 0·2 respectively) in order to provide stable operation on the 1,000 km. transmission lines from Kuibyshev to Moscow. The thrust bearings for the very large machines are stated to be larger than any others produced anywhere in the world, and they have outside friction surface diameters of up to 4,300 mm. To reduce the thermal and mechanical deformation of thrust bearing shoes in bearings carrying loads of up to 3,500 tons, the thickness of the shoes has been increased and their width and length reduced. In umbrella-type units the thrust bearing is designed so that it can be taken apart without the use of a crane. Shoe-type guide bearings are used and lubrication of the thrust and guide bearings is accomplished without circulation of the oil outside the oil baths, as the oil is circulated by the pumping action of the rotating parts of the bearing, without resorting to external pumps and piping. The authors state that this is the most reliable method of lubrication. Special water coils are built in to the oil baths for cooling purposes.

The bearing support brackets are of the parallel-girder type made in the shape of a beam with a somewhat complicated cross-section. The bearing support bracket is the easiest to manufacture and has a very simple load and deflection diagram, while the stresses in the welded seams are as small as possible. However, for very large loads the authors state that a spider type bearing support bracket is used.

In general the diagrams given in the Russian paper show that the designs are conventional and do not present any unusual features.

Power Transmission

Turning now away from the alternator aspect, we may discern certain broad trends in regard to power transmission matters. First, there is the question of voltage level for long-distance power transmission. In past CIGRE conferences the general tenor of the discussion has been that whatever voltage level is under immediate consideration it has been generally

agreed that a higher level would be needed as distances and powers increased. Thus previous CIGRE reports have dealt with, first, the experience gained while operating at the highest level yet achieved, and second, with research and development work for achieving a still higher level. With one exception, the second category was absent in this year's proceedings.

The Swedish pioneering work in regard to 380 kV development was brought to a successful fruition some three years ago, when the first 380/400 kV lines were commissioned. This voltage level has now been generally accepted as practicable for use in any country, under any type of atmospheric conditions, or for any type of route. It is expected that by the end of 1956 there will be a total of 1,670 circuit miles of 400 kV line in operation in Sweden, while parts of the British 275 kV grid system have been designed for later conversion to 380 kV. In an atmosphere which in certain industrial regions reaches a degree of pollution exceeded scarcely anywhere in the world, the fact that British engineers, with their usual conservative outlook, have agreed to the use of this voltage, is sufficient proof that its main problems are regarded as being solved.

In France 220 kV lines are being built so that they can be converted to 380/400 kV in the future, and this process of planning for future conversion to the 400 kV level is also taking place in Germany, Italy, and Switzerland. In Canada a line designed for 345 kV is being built and this is also the case in the United States. It is in the United States that the single exception mentioned above occurs. Mr. Philip Sporn, of the American Gas and Electric Service Corporation, stating that one American power company is seriously investigating 440 kV. No Russian paper was presented this year on extra-high-voltage transmission lines, but in 1952, the previous CIGRE Conference, the Russian engineers present gave particulars of 1,000 km. long 400 kV lines stated to be under construction. In Japan a 275 kV system has been commissioned and research work is being undertaken for still higher voltages, while in Australia 330 kV has been adopted.

Thus it may be stated that the 400 kV level has been successfully achieved; and it was suggested in one or two quarters that no higher a.c. voltage will ever be needed, or, even if needed, would not be practicable, either economically or technically.

There was naturally some discussion as to the influence of atomic power stations on the need for long-distance transmission schemes in the future. Although not mentioned in the official discussions, many private conversations which the writer had with transmission engineers from many parts of the world indicated that the coming of large-scale atomic power development would not militate against the need for more transmission lines of greater capacity and longer length, but would rather tend to extend their use, since atomic power stations would have to be situated in remote areas and would therefore be few in number and large in size, the capital cost of the shielding required prohibiting the installation of a large number of small units close to the load centres. On the other hand, another and more sinister aspect of atomic development, the perfection of the hydrogen bomb, was thought in some quarters to have made national power authorities more conscious still of the need for an even greater degree of electrical interconnection. The experience of Great Britain during the second World War, when intense aerial bombardment did not result in the shutting down of any significant number of consumers at any time, due to the great facility of interconnection existing through the National Grid, was often referred to in these discussions.

Thus the 400 kV level, with the use of series capacitors at one or even more points along the line, to increase the transmission capacity, appears at the moment to be the highest projected or practicable level of power transmission; and since a number of factors, including the need for submarine cable links and the transmission of power in increasing quantities in closely built-up areas have created pressing problems in many countries, the cable position may provide another limitation to voltage increase in the future. This was demonstrated in a paper by *M.* L. Domenach, of Cables de Lyon, in which he said that by reason of the high dielectric losses in 380 kV cables (of which there exists one example, on the Swedish network) the ratio of the powers transmitted by cables at 380 kV and 220 kV is only approximately 1·5 to 1, for equal temperature rise and conductor cross-section. With a power factor reduced to 0·003, the voltage of 550 kV would appear to be the limit for the use of present-day cables for a.c.

The 400 kV voltage level enables distances of up to 1,000 miles to be contemplated, although there are still problems connected with stability and efficiency of load transference to be solved. But if power has to be carried across the sea or under a wide river or estuary, the a.c. cable limit of about 40 miles, no matter what the voltage, has still formed an insuperable barrier for the transmission engineer. In certain countries, particularly where there are offshore islands with large hydro-electric potentials, this problem may become increasingly serious.

High Voltage D.C. Cables

We now turn, then, to the next broad facet of the 1954 Conference, which concerns the breaching of this barrier by the use of high voltage direct current for power transmission. In this field the brilliantly successful research work, carried out over two decades, by the Swedish firm of ASEA and in particular by Dr. Uno Lamm, reached its culminating point in March of this year, when hydro-electric power from the mainland of Sweden was for the first time transmitted to the Island of Gotland, 62½ miles off shore, by means of high-voltage direct current. A single cable is used, operating at 100 kV to earth, the return current passing through the sea.

The Gotland scheme has operated successfully since its inception, although a cable fault a few days after it was switched on caused a brief interruption in supply. This cable fault was caused by mechanical damage, possibly due to a ship's anchor, and cannot be counted as anything to do with the fact that it was a direct current cable. In practice, the fault proved an advantage of direct current, not generally appreciated, in that by the instantaneous action on the grids of the valves at the rectifier and inverter installations, a fault can be "supressed" without creating the slightest disturbance by way of surges on the a.c. systems at either end. Compared with the minimum operating time of three cycles for the fastest a.c. breaker, the advantage of electronically controlled

circuit breaking is obvious.

Due to a breakdown in the local hydro-electric station on the mainland, the Gotland scheme was temporarily reversed to supply power back to the local mainland network from the steam station on Gotland, and this enabled unexpected operational tests on a commercial scale to be carried out.

The advantages of direct current are briefly as follow:—first, there are no distance limitations, whether for overhead lines or for underground or submarine cables, and so it may be said that once further installations have been commissioned, the last barriers between transmitting power from any one point on the earth's surface to any other point have now been broken down. Secondly, for a length of over about 200 miles and for a power of about 200 to 300 MW, the direct current schemes show an economic advantage, since the additional cost of the substation equipment at each end is then offset by the reduced cost of the transmission line itself. The need for two conductors in place of three and the fact that a given insulation (whether overhead line porcelain insulators or cable paper) can be used to much greater advantage also provide cogent arguments for the use of direct current.

Thirdly, there is an important aspect of direct-current operation which is of special interest to hydro-electric engineers. With an a.c. network, there can be no disparity in frequency between generators at the two ends of a long transmission line. Where hydraulic conditions are such that a slightly lower frequency would be of great advantage, or where it is forced on the operators by reason of water-supply difficulties, the direct-current link would enable this facility to be available without affecting the power flow. The present writer, in taking part in the discussion on this subject, suggested that the British and French Electricity Authorities might care to reconsider the proposed cross-Channel cable in the light of the proved practicability, since the commissioning of the Gotland scheme, of high-voltage direct-current transmission. Not only would the power flow on a given cable be increased three or four times, but the operating problem with two large networks connected by a 100 MW "shoestring," would be greatly minimised. The writer compared the large hydro-electric and thermal generating capacity of France and the even larger thermal generating plant in Great Britain, when coupled by the proposed Channel cable, to two locomotives tied together with a thin cord. To operate so that the cord would not break, was to place an undue and unecessary strain on the drivers. Similarly, in spite of the automatic frequency regulation employed in France (as opposed to the manual frequency regulation common in Great Britain) the National Control Centres of the two countries would have a severe task in front of them if they endeavoured to control their vast systems so as to keep the cross-Channel cable loading within the allotted figure.

In reply, Mr. F. J. Lane, Deputy Chief Engineer (Transmission) of the British Electricity Authority, said that the commissioning of the Gotland scheme would undoubtedly cause complete reconsideration to be given to the technical aspect of the cross-Channel cable.

Mr. J. E. Calverley, of the English Electric Company, said that the commissioning of the world's first high voltage direct current scheme was a landmark in electrical engineering progress, and paved the way to million-volt power transmission.

In a final summing-up of the remainder of the proceedings at this year's Conference, it is worthy of note that there was a strong indication that a lull has been reached in the many controversial matters which had taken up so much time in previous conferences. The impulse testing of transformers, once condemned in many quarters as possibly causing more faults than it detected, is now accepted practice, and all that happened in regard to this matter in 1954 was that the specialists, as always, found detailed points to argue about, mainly concerned with the exact interpretation of particular oscillograms produced during impulse tests. There was, however, a new field of interest in the transformer section when the subject of auto-transformers for very high-voltage systems was brought up. These transformers are used on the British 275/132 kV system and also on the Swedish 380/220 kV system, and in spite of the possibility of undue transference of lightning circuits from the high-voltage to the low-voltage side, the engineers concerned with their operation are satisfied as to their economic and technical advantages. Attention was also directed to the tap changers used on high-voltage transformers, and it was thought that the time might be ripe for the preparation of more detailed specifications in regard to the overvoltages caused by the operation of certain types of tap changer, and to the test voltages which this vital part of the transformer should be called on to withstand.

In the overhead line section, the oustanding paper was one from Canada in which the two-mile crossing of the Kootenay Lake was described. The 170 kV transmission line has been successfully commissioned using galvanised steel conductors of 1·25 in. in diameter and 10,733 ft. in length. In general, the use of twin conductors per phase for very high voltage lines is now approved, and most of the lines designed for ultimate operation at 380/400 kV employ two conductors held apart by spacers. The advantages are greatly reduced corona loss, improved surge impedance conditions and greater transmission capacity.

The cable section had before it the results of three years' experience in America of polythene insulated cables, and it was stated that samples cut out and examined electrically, chemically and mechanically showed that no deterioration whatsoever had occurred. The use of aluminium-sheathed cables for high voltages is now increasing, and the British Insulated Callender's Cables engineers were able to report that they had received an order for the first 132 kV cables of this type ever to be manufactured.

Greater attention is now being paid to the use of computational aids for system planning and particularly for system operation. In the past a.c. network analysers have been widely used for long-term system planning, and for the evaluation of short-circuit currents, as well as for predicting load flows. These machines, however, are expensive and to a certain extent cumbersome, and are not suitable for assisting load despatchers in minute-to-minute system operation. A series of papers from Great Britain showed that the work carried out on this subject has resulted in a relatively inexpensive and simple load-flow calculator or universal network analyser being devised and has been tried out successfully on a part of the

(Continued on page 308)

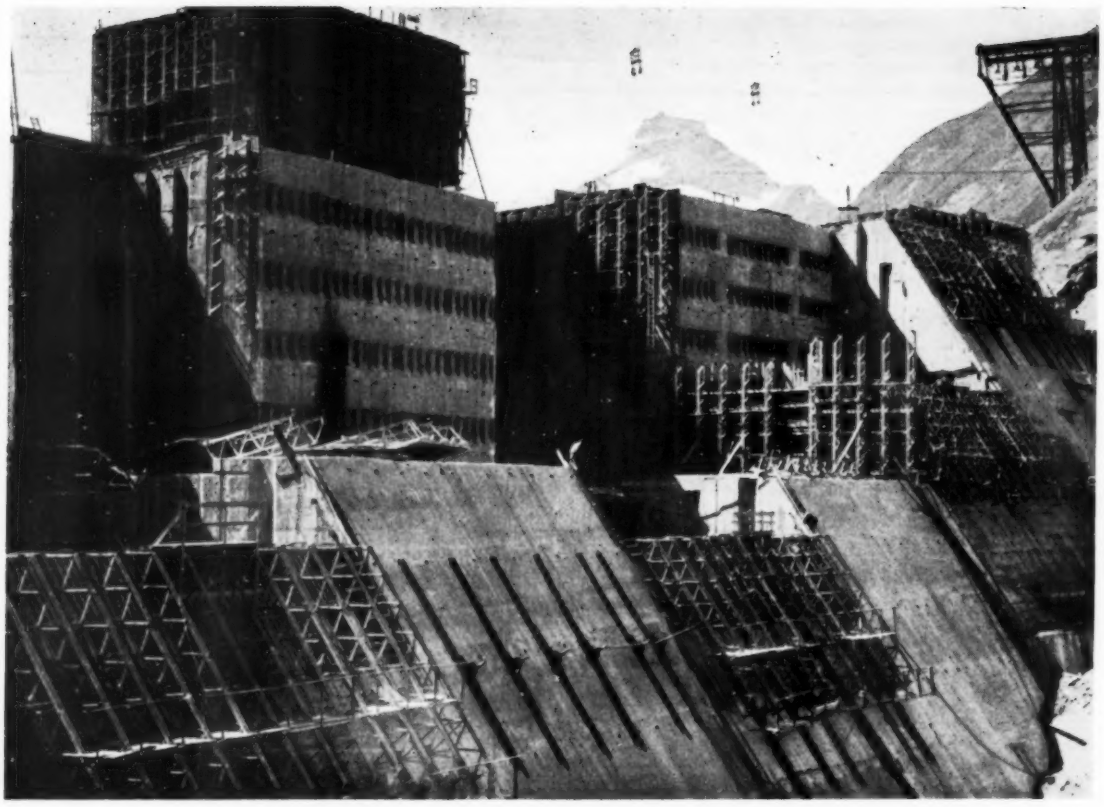


Fig. 1. Mooserboden dam under construction

The Glockner-Kaprun Scheme

P. M. Palmer outlines the main features of this important Austrian development and describes the progress of construction at the time of his visit in the autumn of 1953. When completed in 1957 this development will have a capacity of 332 MW.

PART ONE

THE bringing into full production of the main plant in the Glockner-Kaprun hydro-electric scheme in the autumn of 1951 marked an important step forward in Austria's struggle to become economically self-sufficient. At present this main plant is producing annually 400 million kWh of energy, with a maximum capacity of 220,000 kW, and when finally completed the annual output of electrical energy for the whole Glockner-Kaprun scheme will be 815 million kWh, with a maximum generating capacity of 332,000 kW. Austria is at present engaged in the establishment of modern industries where previously none existed, but she has virtually no coal resources of her own; hence the rapid development of the hydro-electric potential of the country is of primary importance. It is estimated that only 15 per cent. of this potential has so far been exploited and there is still ample scope for new engineering projects.

The Glockner-Kaprun scheme is only one of the several schemes which are at present under construction in Austria but it is typical of the work being carried out throughout the country. This article outlines the main features of the scheme as it exists today and gives a brief description of the work actually in progress.

Location and General Description

The Kaprun valley, in which most of the major installations of the scheme are sited, has its beginning on the northern slopes of the main ridge of the Hohen Tauern mountains and runs due north until it opens out, just below the village of Kaprun, into the valley of the River Salzach which at this point

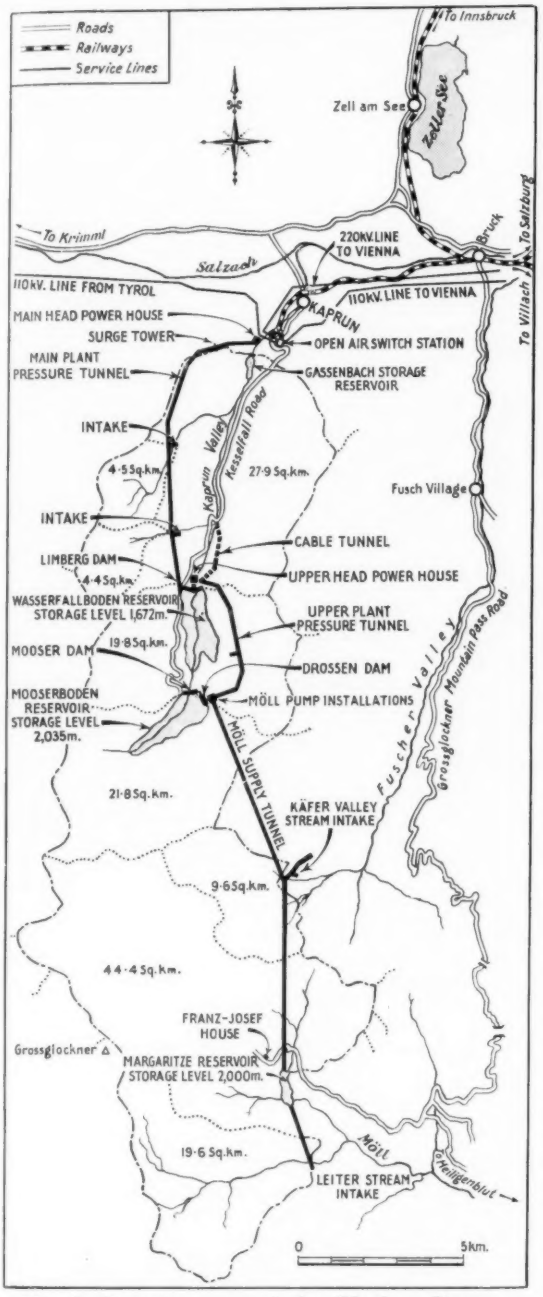


Fig. 2. Location map of the Glockner-Kaprun development showing catchment areas

runs from west to east. (See Fig. 2.)

The hydro-electric scheme in the Kaprun valley is characterised by its storage works, necessary to collect the large summer run-off, due both to rainfall and to the melting of the winter snows, and to store it, ready to meet the peak demands for energy during the winter months. One of the reasons for the final selection of this valley was that it possessed the natural advantages of a large drop in elevation over a short length and also two large natural storage basins, at Wasserfallboden and Mooserboden. In order to utilise to the full all the natural resources of the site an additional compensating reservoir has been created at Margaritze, on the southern slope of the main Hohen Tauern ridge and at the foot of the Grossglockner group, to collect the meltwaters from the Pasterzen glacier and convey them in a pressure tunnel to the Mooserboden reservoir.

Fundamentally the scheme, when complete, will operate by using water from the highest level, at the Mooserboden reservoir (2,035 m. above sea level), in two stages (see Fig. 2). The first, to the Wasserfallboden reservoir at 1,672 m. above sea level, terminates in the upper plant at Limberg, and the second in the main plant at Kaprun (800 m. above sea level), whence the water is returned to the main Kaprun stream. In addition, pumps will be installed at Limberg so that in times of excess flow into the Wasserfallboden reservoir the water can be pumped up into the Mooserboden reservoir and stored there for future use.

The storage at Mooserboden is being created by the construction of two dams, Mooser dam and Drossen dam, one in each of the gorges leading out from the natural basin of Mooserboden on either side of a large outcrop of rock known as the Höhenburg. When these two dams are completed the total useful storage at Mooserboden will be 84·0 million cu. m. At Wasselfallboden a total useful storage of 84·5 million cu. m. has already been created by the construction of the Limberg dam, a concrete arch structure 120 m. high. As the compensating reservoir at Margaritze is at a lower level than the Mooserboden reservoir a pumping station will be built at Möll, on the east side of Mooserboden, to lift the daily flow from the Pasterzen glacier into the Mooserboden reservoir.

From Mooserboden reservoir the water is conveyed in a pressure tunnel to a surge tank immediately above the Limberg dam. Limberg power house stands at the foot of the Limberg dam and water is brought from the surge tank to the turbines in an inclined steel-lined shaft. After passing through the turbines the water is carried through the body of the Limberg dam in steel pipes and discharged into the Wasserfallboden reservoir.

The above works comprise the upper plant of the scheme. From the Wasserfallboden reservoir water is conveyed in a pressure tunnel to the surge tank at Maiskogel and then in four steel pressure pipes down to the power station at Kaprun. The second stage, the main plant of the scheme, is that which was brought into full operation in the autumn of 1951.

These two plants comprise the main scheme, but in addition a small storage reservoir has been created at Gassenbach to supply two house turbines in the Kaprun power house.

Catchment Area

The total catchment area of the scheme (Fig. 2) exclusive of that which supplies the house turbines in Kaprun, is 124·1 sq. km. (30,670 acres). Of this area 19·8 sq. km. drains into the Wasserfallboden reservoir, 21·8 sq. km. into the Mooserboden reservoir, and 44·4 sq km. into the compensating reservoir at Margaritze. In addition, the catchment areas of four small streams are utilised. A total of 8·9 sq. km. drains into the Grub and Zeferet valleys and the run-off from this is diverted into the main

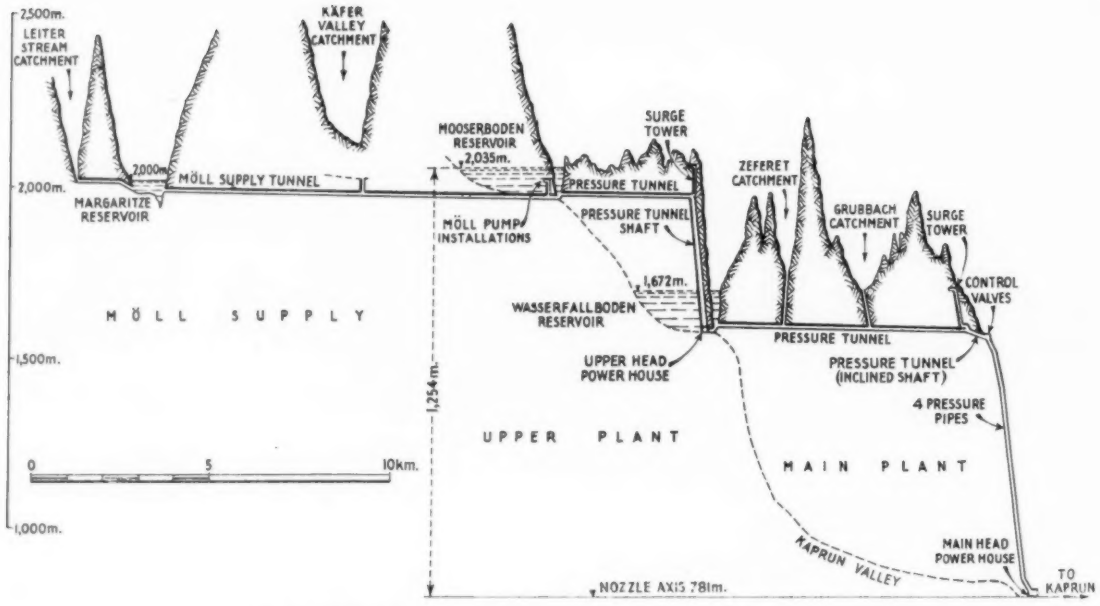


Fig 3. Profile diagram of the Glockner-Kaprun development

plant pressure tunnel between Limberg and Maiskogel, and is therefore only available for the main plant; another 8·3 sq. km. drains into the Käfer valley and this run-off will be diverted into the pressure tunnel between Margaritze and Mooserboden, thereby being available for both plants. Finally, it is intended that the run-off from an area 19·6 sq. km. in extent which drains into the Leiter stream shall be diverted into the Margaritze reservoir through an unpressurised tunnel 1·8 km. long. The creation of the compensating reservoir at Margaritze, making available the run-off from the Pasterzen glacier and the Leiter stream catchment, will more than double the total volume of water available for the generation of electrical energy.

The total average annual run-off from the above catchment area is 238·7 million cu. m. (193,600 acre ft.) and the run-off from the individual catchment areas is shown in Table I. This table also shows the large difference between summer and winter run-offs.

Table II gives the annual rainfall figures for the various catchment areas and also the percentage of run-off estimated to come from glacier meltwater. Rainfall measurements for the area have been recorded from 1930-34 and from 1938-39.

When construction is complete the total maximum useful storage provided by the two reservoirs at Wasserfallboden and Mooserboden will be 168·5 million cu. m. Table I shows that the average summer run-off is 209·8 million cu. m. and the average winter run-off 28·9 million cu. m. Assuming full use is made of the available storage, then 41·3 million cu. m. of water will be available in the summer and 197·4 million cu. m. in the winter for the generation of power.

TABLE I. RUN-OFF FROM GLOCKNER-KAPRUN CATCHMENT.

Catchment Area	Run-off million cu. m.		
	Summer	Winter	Total
Kaprun river	82·3	11·3	93·6
Zeferet stream	8·3	1·1	9·4
Grub stream	6·3	1·0	7·3
Möll and Leiter streams ...	99·6	12·8	112·4
Käfer stream	13·3	2·7	16·0
	209·8	28·9	238·7

TABLE II. RAINFALL ON GLOCKNER-KAPRUN CATCHMENT.

Catchment Area	Run-off from Glaciers %	Annual Rainfall in.
Kaprun valley—Mooserboden ...	54·0	102
" " —Wasserfallboden	34·6	89
Zeferet stream	54·0	91
Grub stream	0·0	69
Möll	60·0	83
Leiter stream	7·0	54
Käfer stream	61·0	99

Upper Head Plant

The main structures comprising this section of the scheme are the Mooser and Drossen dams, which impound the water in the Mooserboden basin; the Margaritze and Möll dams forming the compensating reservoir at Margaritze: the Möll tunnel and pump installations, and the pressure tunnel from Mooserboden to Wasserfallboden. By the end of September 1953, the Margaritze and Möll dams had been completed but the remainder of the work was still in course of construction.

Mooserboden. Mooserboden is a large natural basin beginning under the Karlinger glacier and blocked at its northern end by an outcrop of rock known as the Höhenburg. Water from the Karlinger glacier has cut deep gorges on either side of the Höhenburg and it is across these that the Mooser and Drossen dams are being constructed.

The gorge on the east side of the Höhenburg is fairly symmetrical and will be blocked by an arch dam, arched in plan and in vertical section, known

Fig. 4. Mooserboden dam under construction, viewed from upstream

as the Drossen dam. The west gorge is not nearly so symmetrical and it has been decided to close this side with a gravity dam. The dam is arched in plan but the arching effect has been ignored in designing the profile. The rock in the abutments on the Höhenburg, both of the Mooser dam and Drossen dam, is very broken and extensive grouting will have to be carried out.

When complete the two dams will impound 86 million cu. m. of water. Drossen dam will be 95 m. high and Mooser dam 100 m. A total of 210,000 cu. m. of overburden and 300,000 cu. m. of rock have been excavated and it is estimated that together the two dams will require approximately 1,000,000 cu. m. of concrete.

The spillway and intake levels are designed to be 2,035 m. and 1,960 m. above sea level respectively.

Mooserboden-Limberg Tunnel. The tunnel from Mooserboden reservoir to Limberg power house is designed in two sections. The first, from Mooserboden to the surge tank above Limberg, is a concrete-lined pressure tunnel, 4·48 km. long, running along the east side of the Wasserfallboden. The tunnel has an internal diameter of 3·30 m. at Mooserboden, reducing to 3·26 m. at the surge tank, and a fall of 0·6 per cent. The actual surge tank, as at Maiskogel, is excavated out of the rock. The turbines in Limberg power house and the surge tank are connected by a steel-lined pressure shaft 0·67 km. long and with a gradient of 65 per cent. This shaft has an internal diameter of 2·90 m. at the surge tank, reducing to 2·50 m. at the entrance to the power station, and a maximum discharge of 36 cu. m. per sec. The shaft ends in a single bifurcation into two penstocks which carry the water to the two turbines in the power house.

Limberg Power House. This is a reinforced-concrete structure continuous with the downstream face of Limberg dam and at the moment of writing is nearing completion.

The power house will have two main machines, each comprising an 85,000 h.p. Francis turbine running at 500 r.p.m., and coupled to a 62,000 kVA generator working at 10 kV. Each generator will be connected to a 63,000 kVA transformer stepping up the voltage to 110 kV.

Coupled in parallel with the turbine will be two pump installations, each of 78,500 h.p. and having a maximum discharge of 16·4 cu. m. per sec. These

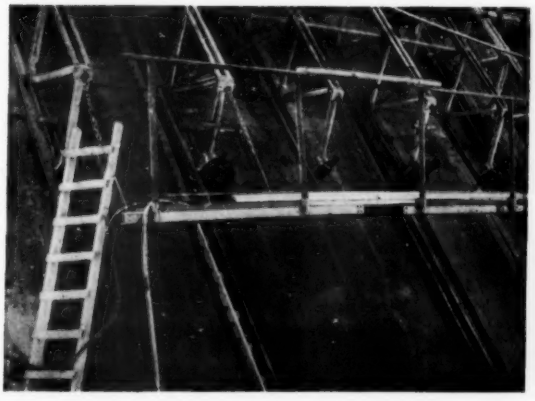


Fig. 5. Detail of shuttering to downstream face of Mooserboden dam

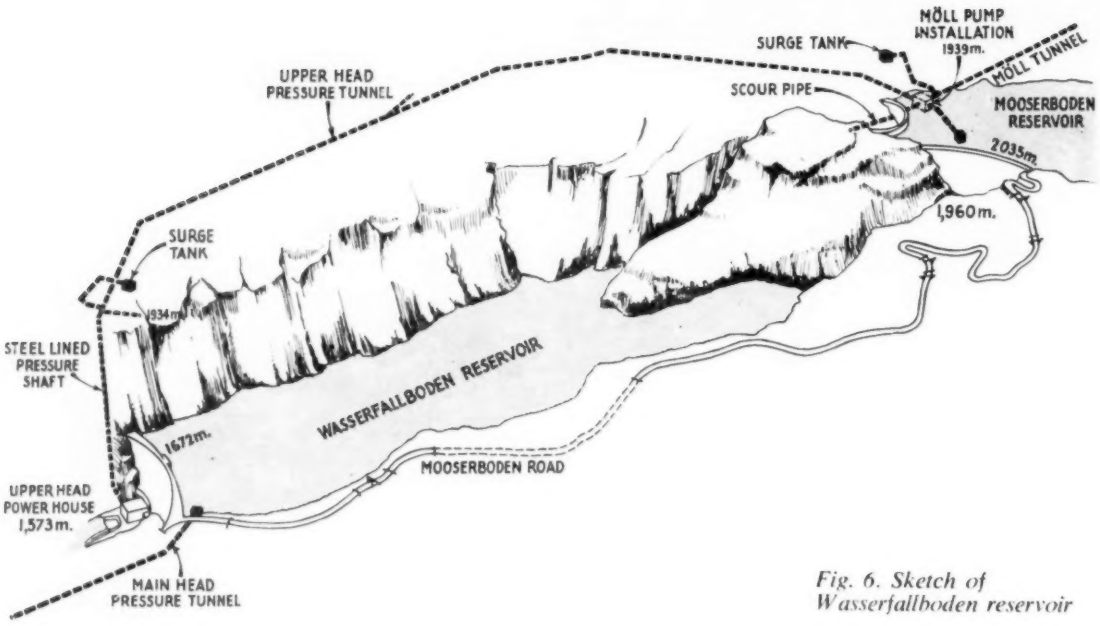


Fig. 6. Sketch of Wasserfallboden reservoir

Fig. 7. Steel lining pipes ready for hauling up inside of Mooserboden pressure tunnel

will be brought into operation in times of excess flow into the Wasserfallboden reservoir, to pump water up to the Mooserboden reservoir where it can be stored ready to meet peak-load demand during the winter months. It is intended also to install in Limberg two transformers to serve the Möll pumps. Each will have a capacity of 12,500 kVA and step down the voltage from 110 to 10 kV.

The installation will be completed by two house machines, each consisting of a Pelton wheel running at 1,000 r.p.m., developing 350 h.p. and coupled to a 350 kVA alternator developing 260 kW at 400 V.

Margaritze. The compensating reservoir at Margaritze lies on the eastern slopes of the Grossglockners, at the foot of the Pasterzen glacier. A storage of approximately 4 million cu. m. has been created by building two dams, the Margaritze and Möll dams, across the beds of the streams of the same name which flow on either side of the hill called Margaritze.

The Möll stream flows through a deep, narrow gorge on the south side of Margaritze and it was decided to block this opening with an arch dam. The resulting structure is both daring and original in its design. It is small by comparison with the Limberg dam but owing to its extremely thin profile and resulting economy in concrete, it is one of the most spectacular engineering structures of the whole scheme. The mid cross-section thicknesses are 7·5 m. at the foundation and 3·0 m. at the crown, and the total volume of concrete placed was 35,000 cu. m. The dam is 90 m. high and 170 m. long at the crown.

The gorge on the north side of Margaritze is not nearly so deep, and the Margaritze dam is of the more conventional gravity type, arched in plan. The total height is 40 m. and the length along the crown 172 m. It is 2 m. wide at the crown and the total volume of concrete placed was 33,000 cu. m.

Möll Tunnel. The largest single piece of construction work entailed in the creation of a compensating reservoir at Margaritze is the driving of a pressure tunnel from Margaritze to Mooserboden. When complete this will be 11·6 km. long and have an internal diameter varying from 2·9 m. to 3·4 m. The tunnel is driven to a fall of 3·4 per cent. and has a maxi-

mum discharge of 20 cu. m. per sec. The run-off from the Käfer valley catchment area is diverted into this tunnel at kilometre 5·5. Eventually it is intended to drive an unpressurised tunnel 1·8 km. long from the Leiter stream to Margaritze and thus divert the run-off from the Leiter catchment area into the Margaritze reservoir. The Möll tunnel is being driven from three headings, namely from Mooserboden southwards, from the Pasterzen northwards (beginning in the vicinity of Glockner-Haus) and finally from the centre of the tunnel line (from the Käfer valley) in both directions, that is, to the north and south.

Möll Pumping Station. For the greater part of the year the water at Margaritze will be below the level of that in the Mooserboden reservoir, and the water from the Pasterzen glacier and the associated catchment will have to be pumped up into the Mooserboden reservoir. The pumps will be housed in the Möll tunnel where it enters the Mooserboden reservoir and a pump house with the overall dimensions 41·2 m. × 17·3 m. × 17·8 m. has been excavated in the mountain side.

When complete the pump house will have two machines, each consisting of a horizontal double-entry centrifugal pump running at 500 r.p.m. and driven by a 10 kV, 6,700 kW motor. The maximum discharge of the whole installation will be 20 cu. m. per sec. against a head of 80 m.

Gassenbach Storage Reservoir. The two house turbines in the Kaprun power house are supplied from a small daily storage reservoir at Gassenbach which has been created by building a gravity dam 20 m. high across the Kaprun river at this point. The total daily storage of the reservoir is 200,000 cu. m. and the dam has a crest spillway for discharging all excess flow. A spun-concrete pipeline, 80 cm. in internal diameter and approximately 400 m. long, carries the water to the turbines. The maximum head under which the turbines operate is 65 m. and the maximum discharge of the pipe is 1 cu. m. per sec.

(To be continued)

Book Reviews

"Les Installations Hydro-Electriques en Suisse" (Hydroelectric Developments in Switzerland). Edited by P. Meystre, Chief Engineer of the Lausanne Electricity Service, in co-operation with the Swiss power undertakings. Published by Imprimerie Vaudoise, Lausanne, 8·3 in. by 11 in., 174 pp., 116 ff. Price in Switzerland Sw. Fr. 15·00.

This interesting collective work constitutes a comprehensive survey of the evolution of hydroelectric power in Switzerland during the first half of this century. In part I, chapter I, after brief considerations on power as a world problem, the general conditions obtaining in Switzerland are discussed. The expansion of electricity generation together with its characteristics and future prospects is reviewed in chapter II, while chapter III deals with organisation, separate sections being devoted to the major public-utility enterprises, such as those of the Zurich, Geneva and Lausanne Corporations, the Aar-Tessin (ATEL) concern, Compagnie Vaudoise and Entreprises Electriques Fribourgeoises.

Developments proper are described in part II, the initial chapter dealing with general characteristics such as hydrographic conditions, types of development and equipment. Chapter II gives the description of such well known recent installations as Wassen, Lavey, Gondo, Oberhasli, Rossens-Hauterive, Salanfe and others—Châtelot, Mauvoisin, Grande Dixence, Rheinau, and so on. Other developments in progress in 1952 are reviewed in chapters III and IV. An outline of the financial aspects of Swiss development is given in chapter V, and the future of the electrical industry and the resources available are discussed in chapter VI; from the conclusion of this chapter, it appears that hydroelectric power ensures no more than 20 per cent. of Swiss requirements, while 70 per cent. have still to be covered by fuel imports. Interesting details on the plants wholly or partly controlled by the Swiss State Railways and on the Göschenen project are brought out in chapter VII; the importance of hydroelectric power in this connection is best emphasised by the fact that at the end of 1951 no less than 96·1 per cent. (2,800 km) of the Swiss railway network had already been electrified. Notices on electrical equipment supplied by leading Swiss manufacturers fill the last part of the book.

This work, neatly printed on art paper with a profusion of excellent photographic and line illustrations, gives a very clear idea of the scope of Swiss achievements in hydroelectric development, and of the unceasing efforts which have been made to utilise to the widest extent the resources still available. The urgency of this task derives both from the geographical situation of the country and the scarcity of its fuel resources, not to mention the experience of two world wars.

A few sections of this survey, devoted to installations in German-speaking Switzerland, and printed in German, are followed by a French summary.

Billings and Water Power in Brazil. By Adolph J. Ackerman. Published by the author and distributed by the American Society of Civil Engineers, 33 West 39th Street, New York, U.S.A. 1953. 10½ in. x 7½ in. x ⅝ in. 128 pp. Illus.

It has been given to few engineers to dominate the power supplies of a country to the same extent that A. W. K. Billings did in Brazil between the years 1921 and 1949, when he retired, a period of almost three decades. His task was to provide economic power for a country of vast dimensions, in which transport was often extremely difficult, in which there was a total absence of data on which to base estimates and in which capital was scarce.

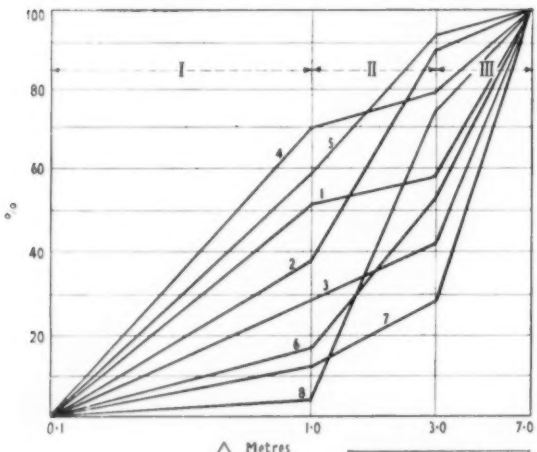
The way in which all these obstacles were overcome and in which Brazil was provided with a series of brilliantly conceived hydro-electric stations is very interestingly told in the present volume. Mr. Ackerman wisely emphasises the personal aspects of this achievement, for it was largely inspired by a technologist who, among other valuable gifts, had the rare ability to inspire confidence and enthusiasm in others. It makes an impressive story and one which Mr. Ackerman tells with distinction.

New Experience in Mass Concrete Construction—II

This article discusses certain improvements in mass concrete technology which have been adopted in important hydro-electric structures in Austria.

By DIPL. ING. DR. JOSEF FRITSCH

IN this particular case only one variable, that of the additional sand, had to be determined. Another example will show the procedure adopted in the construction of the Jochenstein Danube power plant to ascertain the best composition of the sand. At this site fine sand is available in the grain-size groups from 0.1—1 mm. and 1—3 mm., and coarse sand from 3—7 mm. To find in such a case the optimum ratio of these three size ranges, numerous concrete specimens with widely different gradations were made. The gradation above 7 mm., of minor effect on the optimum value, remains unchanged in all the tests. The proportion of the three sand fractions were substantially changed for each test. For each of the eight tentative settling curves (Fig. 7) the cement requirement was determined by the process already explained and plotted in a ternary diagram. Here points of equal cement requirement can be logically connected to give the region below 230 kg. per cu. m. of concrete, where the absolute optimum values of the settling curves must be expected. Here again it is not necessary to test arbitrarily adopted gradations to obtain the optimum value, which is found more quickly and accurately by the graphical method explained.



SIEVE CURVE	CEMENT REQUIREMENT
1	250 kg./cu.m.
2	265 " " "
3	246 " " "

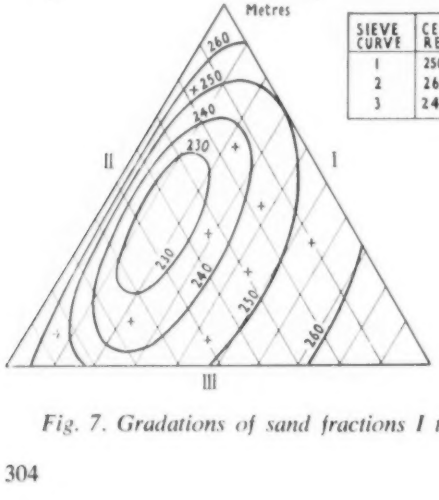


Fig. 7. Gradations of sand fractions I to III

These procedures are more easily carried out than described. One laboratory can easily conduct on one working day ten individual tests, together with all the incidental work, so that an optimum value can be determined within a very short time.

Fig. 8 shows, as an additional example, the procedure for determining which of two cements available is the more economical for a certain strength of concrete required. We face such a problem mainly when Portland cement is to be mixed with a pozzolana cement such, for instance, as in the case of the Jochenstein Danube power plant to which we have referred. Previously the cube-compression strength was used almost exclusively as a yardstick for such comparisons. Now we also consider the difference in the cement-paste requirement of the grain mixture. The example shows that a typical mixture of Portland cement and pozzolana cement has a different strength in relation to the water-cement ratio and shows also an essential difference in cement requirement and price.

To determine which cement is most economical for a certain strength, the following procedure is adopted (Fig. 8): The afore-mentioned relation between strength and water-cement ratio for the job concerned is plotted in Section 1, Fig. 8, for the two cements to be compared. The value thus found is then used to determine the water-cement paste requirement in the concrete test, which is entered in Section 2. Section 3 shows the price of the two cements, and Section 4 represents the direct relation between the required strength of concrete and the price for each of the two cements. If the entire calculation is repeated for cement mixtures with different proportions of pozzolanas, the particular proportion of pozzolana can be determined to give the most economical mixture for each strength of concrete.

Consistency

When the concrete-testing laboratory has thus determined the gradation and cement, the workers on the job must take care that the workability and degree of compaction always reach optimum values.

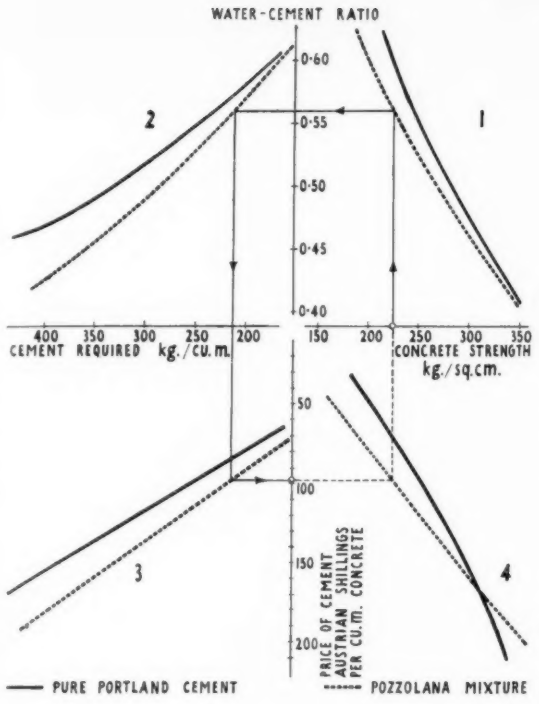


Fig. 8. Determination of cement required for different strengths of concrete

Even where the required strength of concrete is in fact obtained, the degree of compaction must be adhered to. Concrete which in the fresh state has been compacted to less than a practically perfect degree, for whatever reason, may still have a moderate compression strength required, but may not have a good resistance to freezing. Even most exact freezing tests show such great variations that it is difficult to derive laws which clearly indicate the relation between the resistance to freezing and other determinable properties of concrete. On the other hand the influence of the void ratio of a perfectly compacted concrete to resistance to freezing can definitely be ascertained. Fig. 9 is a synopsis of comparative results obtained in our freezing tests.

Thus the degree of compaction actually achieved on the job assumes special importance. It depends substantially on the workability and stiffness of the concrete when placed.

In the erection of the Limberg dam of the Tauernkraftwerke AG., Kaprun, a concrete was specified which would be so dry that a heavy internal vibrator could just be introduced without difficulty, whereas, on the other hand, the vibratory treatment was to render the mixture so mobile that when the vibrator was pulled out the concrete would just spontaneously close the opening left. Obviously a concrete mixture as dry as possible, as had been used in the war in the Eckertal dam in the Harz, enabled a maximum binding force to be obtained from the cement, though only if practically perfect compaction is actually achieved at all points of the structure. Such a requirement can be fulfilled with safety with a somewhat softer concrete. For this reason most foreign companies, mainly American, have never worked with mixtures as dry as those used on these two jobs.

The responsibility for adhering to the practically complete compaction of the fresh concrete during placing tends to be relieved by the preparation of a somewhat softer concrete. On American jobs this has caused the vibrator to be pulled through, as shown in Fig. 10. We reject such soft consistency and generally introduce our one-man vibrators at the boundary of the range compacted during the foregoing step. Fig. 11 shows the rough, coarse consistency of the uncompacted concrete, and the smooth, but not watery, surface of the compacted concrete. In emptying the buckets care should be taken to prevent the coarser stones from rolling on the surface of the previous set —the most delicate point of our mass-concrete structure—where they would render the good bonding of the fresh concrete more difficult (Fig. 12). To this end the buckets may be discharged not directly on to the surface of the old concrete, but into the freshly dumped concrete, if possible (Fig. 13).

Upper Particle-Size Limit

In discussing the placing of the concrete the upper particle-size limit must not be overlooked. It is interesting to study the development of mass-concrete engineering in that respect. The first endeavours to increase the particle size were made in the period of cast concrete. It was then felt, quite correctly, that it meant an unnecessary departure from the still unachievable model given by Nature when the building material is mixed with too much water. This led to the first improvement, namely the embedding of the larger stones in the soft mass. This practice was satisfactory mainly because the soft concrete fully ensured the connection of the embedding mass on all sides.

When the technique of soft, cast concrete finally developed to tamped concrete, the embedding of big stones offered little security. Investigations showed that, mainly below the stones, the compaction was not fully effective, so that air and water accumulated and impaired the indispensable adherence. Moreover, the separate introduction of the stones with separate equipment was rather costly.

It was consequently hoped that the next step in the

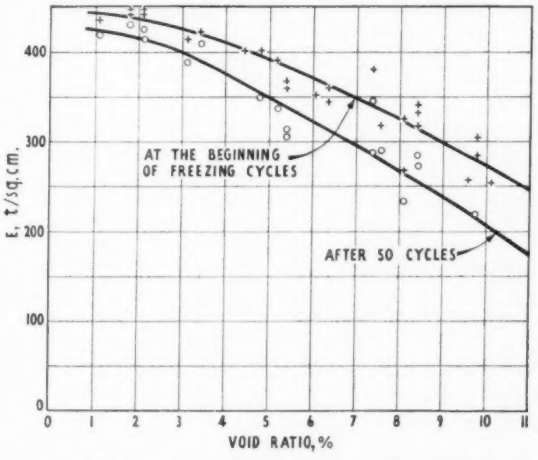


Fig. 9. Effect of void ratio on sand modules of elasticity and resistance to freezing

line of progress—vibrated concrete—owing to its coarser, drier consistency, would eliminate the need for embedding stones. At first, however, practice with stiff mixes was hampered by the low power of the vibrators then available (Fig. 14).

Further progress had to await the construction of more-powerful internal vibrators, which were initially developed in America and Sweden and enabled the coarser grains to be worked in the normal way. The upper particle-size limit was thus increased progressively. It is typical perhaps that this development went at first far beyond its objective. Fig. 15 shows a large-sized particle used on a foreign job, corresponding to a sieve opening of 240 mm. diameter. Retrogression soon followed, as investigations showed the limits beyond which a snug contact with the stones in mass concrete could not be ensured even with the most powerful vibrations. Today we know that modern concrete-preparation plants and heavy internal vibrators can work particles corresponding to a sieve opening of about 15 cm. in diameter. This size is considered the optimum on many jobs throughout the world (Fig. 16).

This did not put an end, however, to endeavours towards the working of an increasingly coarse-grained mixture. The desire for a heavier largest-size particle was understandable, because it reduces the require-

Fig. 12. Rolled out coarse aggregate

Fig. 13. Emptying the concrete bucket into the fresh mix to avoid rolling out

Fig. 10. Dragging the vibrators through the concrete on an American job

Fig. 11. Immersing the vibrator

Fig. 14. Vibrating in fine concrete

Fig. 15. Vibrating coarse concrete

ment for cement and fine concrete. As the size of the stones used increased, the finer mix could be made increasingly richer and still require less cement by volume of concrete, as long as a uniform mechanical working was ensured. As has often happened in the history of technology, further development reverted to a previous expedient—in this instance the separate embedding of individual pieces in the basic mix. As an example, we may refer to the tentative embedding of individual rocks into the completely compacted mass concrete of the Limberg dam[7].

At this time mechanical engineers began to provide vibrators which represented a fundamental departure from previous developments, and succeeded in enforcing effects with weights of several tons[8]. At the present time technological development seems to have reached a limit, but it is unwise to prophesy in this matter. Concrete still contains much more water than is necessary for the chemical combination of cement, and this surplus water provides a further stimulus for designers of construction equipment and concrete technologists to go one better and approach some of the examples found in Nature.

Surface of Concrete

Passing reference may be made to a former practice, when mass concrete was far from its present uniformity and quality, of protecting the surface of hydraulic structures by a facing of natural stones. Many of our older hydraulic works are faced in that way. This practice has now little justification, and fell out of favour as the quality of the concrete itself was improved.

As tamped concrete was introduced, a concrete core consisting of a cheaper mixture was incorporated inside large gravity walls, and covered with a layer often several metres thick to protect the structure from atmospheric influences. Gradually the thickness of the high-quality shell was reduced until it became a mere shuttering to contain the bulk concrete. This system was mainly used in France, on the La Girotte job, and later at Bort les Orgues (Fig. 17), and although it has proved satisfactory in practice, it can be objected that the concrete shell, when completely hardened, cannot follow the movements of the fresh concrete during its shrinkage period, so that separation must to some extent be feared. To circumvent this possibility we have made a model of concrete shuttering panels anchored not by a thin strut of steel embedded in the concrete body, but by an embedded block; this guards against any possibility of separation because the anchoring elements are virtually foreign bodies in the concrete mass (Fig. 18).

Summary

The improvement effected in the quality of concrete achieved in our big jobs, compared with the so-called old classic concrete theory, is due mainly to the following factors:

(1) Simultaneous improvement in quality and gradation of the superfine fractions by removing the dust from the aggregates and the partial substitution of these detrimental particles by artificial air pores. Classification of the finest sand into two or more groups and the separate addition of the fractions in accordance with a settling curve which covers these grain groups.

Fig. 16. Concrete mix with largest particle size corresponding to 15 cm. sieve opening

Fig. 17. Concrete forms used at Bort les Orgues, France

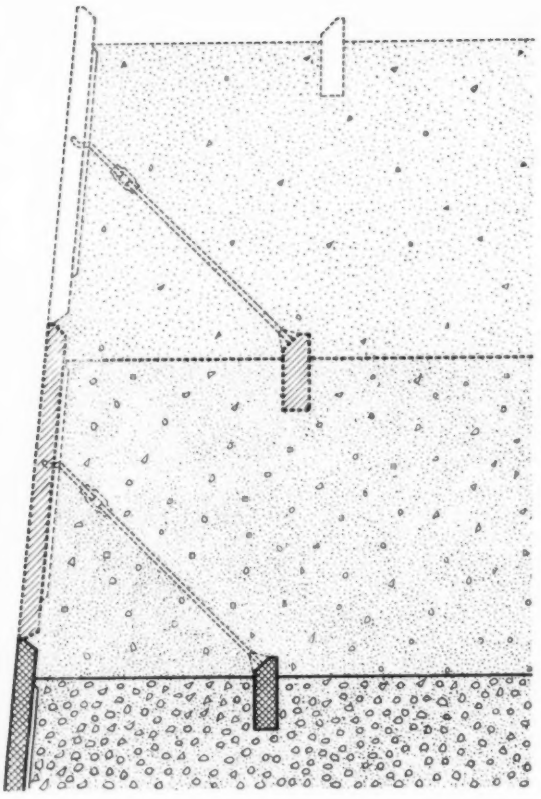


Fig. 18. Lost-form panels of concrete with steel tie

(2) Achievement of the practically complete compaction of fresh concrete on the job by careful control of the composition of concrete with a view to its response to vibration.

(3) Defining the fresh concrete in terms of its water-cement ratio and degree of compaction, and estimating the gradation by the amount of water-cement paste of a given composition required for ideal response to vibration.

(4) Highest concrete quality in the outer layer of the mass concrete, that is concrete shuttering panels.

The observance of these requirements enables the variations in concrete, previously considered inevitable, to be not only reduced but eliminated, and to make best use of the building materials. We are only at the beginning of this trend, but it is already certain that old standards and experience cannot altogether be relied upon in determining new principles. In consequence we must have the means and courage to investigate all basic questions on every new work, and establish independent practices without relying too much on former experience.

From page 297

British Grid system. There was also a paper by Mr. C. P. Holder, of the Metropolitan-Vickers Electrical Company, on a related matter but with special application to the characteristic features of long-distance hydro-electric power transmission schemes.

The 1954 CIGRE Conference attracted 1,550 delegates from forty-five countries and, as usual, there were a number of technical visits of great interest. Principal among these was a visit to the famous network testing station and high voltage laboratory of Electricité de France at Fontenay, where each successive Conference shows new and important developments. This station is now used by switchgear manufacturers from almost everywhere in the world, and although the new testing station recently commissioned by A. Reyrolle & Company, Hebburn-on-Tyne, Great Britain (and which was the subject of a CIGRE paper) is equally important, there are still certain problems in regard to switchgear development which can only be solved by actual network tests. The Reyrolle station, with a short circuit power one and a half times as great as that of any other station, was the subject of congratulatory remarks from many quarters.

Metal Spraying. Under the title "Metal Spraying by the British Wire Process," Metallisation Limited have issued a handsome brochure to show the progress which has been made in protecting metal structures and building up worn parts of machinery by this technique. The brochure, which is fully illustrated, describes how metal spraying can be done either at the works of Metallisation Limited or on site. A wide range of metals can now be successfully applied to structures for protective coatings and for the rehabilitating of worn machine parts—zinc, aluminium, cadmium, lead, copper, molybdenum, stainless steel, etc.

Water Power and the Industrial Revolution

In this article Paul N. Wilson* puts forward the interesting theory that water power had a greater influence upon the Industrial Revolution than the invention of the steam engine

IN an earlier article the author gave a brief summary of the history of water power from the earliest times to the year 1750. He stressed the fact that the growth of industry in Great Britain depended largely upon water power and hazarded the suggestion that this was a major element in bringing about the Industrial Revolution. His purpose now is to investigate the extent to which water power was used in the second half of the eighteenth and first half of the nineteenth century, and to evaluate, so far as may be possible, its effect upon industrial development during this period.[1]

The Background of the Industrial Revolution

In 1700 England was largely an agricultural country, but capitalist industry in mining, the iron trades, textiles and chemicals was steadily gaining in importance. The woollen and worsted industry was still looked upon as the mainstay of the export trade: the Lord Chancellor sat—literally—upon a "woolsack," and the towns which depended upon wool were hedged about with restrictive practices designed to safeguard their trade at almost any expense. The silk industry was assisted by successive governments but caused little concern to the wool traders. Only one small cloud bearing the name "cotton" drifted over the eastern horizon, and steps were soon taken to ensure that this should not interfere with the stable industry. In 1702 an Act was passed prohibiting the import of cotton goods from India, but nothing was done to check the spinning and weaving of cotton in England.[2] The cotton trade was closely bound up with the slave or "Africa" trade. At first cotton goods were imported from India by the East India Company and were used to barter for slaves in Africa. It was then found that cotton clothing was required by the slaves in the West Indies and America, and that raw cotton could profitably be imported from America in "Slavers" returning empty to Liverpool on their way back to the west coast of Africa. Two hundred years ago scientific market research was unknown, but the Lancashire traders were shrewd, and they quickly grasped the fact that if they could not get their cotton goods from India, they had better make them near Liverpool.

In the non-corporate towns of Manchester, Bolton, Rochdale, Bury and Blackburn there were no special restrictions on trade such as existed in the old "woollen" towns of Wigan, Lancaster, York, Kendal and Chester. In these new towns the cotton manufacture flourished, but by 1750 it was becoming clear that the demand would not be met unless the output of the spinners could be enormously increased. The hand-loom weavers could keep pace, but, as a general rule, linen had to be used for the warp, as great difficulty was experienced in spinning a thread long and strong enough for this duty. The importance of the rapidly-developing cotton trade cannot be overestimated in any consideration of the Industrial Revolution. It was the "bread and butter line" which was to sustain our other new industries and trades.

At this stage it might be as well to review the forms of motive power available to industrialists. The most important was the water-wheel, and this was used wherever possible. Windmills were used for corn grinding and pumping in the fens. For a duty where the total number of hours worked in a year was commensurate with power available during certain working hours per day in a year they were a sound economic proposition, but they could not be put to normal *industrial* use. The horsemill was reliable, but the power was very small.[3] The steam engine was in its infancy. The first economic steam pumping engine was invented by Thomas Newcomen in 1712. This was a reciprocating pump, generally used in Cornwall for dewatering mines, but later adapted for other purposes.

Assuming that the progress of the Industrial Revolution can be roughly gauged by the increase of raw cotton imports into Great Britain, the curve given in Fig. 1 may be of some help in correlating the dates of mechanical developments with the cotton industry.[4]

The Demand for Industrial Power

The first large textile mill was built while the cotton industry was in its infancy. This was Thomas Lombe's Silk Throwing Factory set up on an island in the River Derwent at Derby and opened about 1721. Even judged by modern standards it was a large building, 500 feet long, six storeys high, and having 460 windows.[5] This mill was driven by water power and judging from the description of the machinery, the power developed by the wheel (or wheels) must have been considerable. It may have served as a

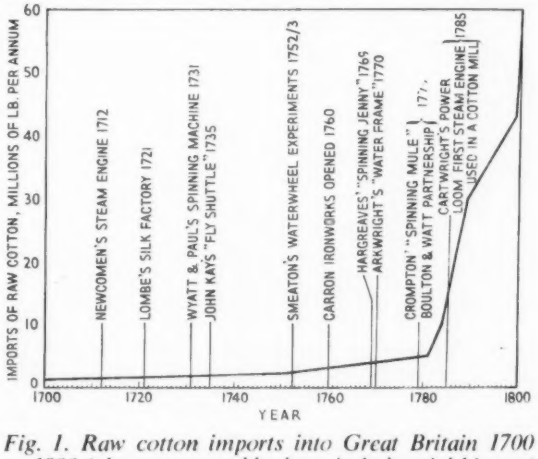


Fig. 1. Raw cotton imports into Great Britain 1700 to 1800 (also some notable dates in industrial history)

* Chairman, Gilbert Gilkes and Gordon Ltd.

Fig. 2. Waterwheels at Bakewell, Derbyshire, on the site of those driving Arkwright's Mill opened in 1777. The larger wheel was built in 1827 and probably replaced Arkwright's original wheel

(By courtesy of The D.P. Battery Co. Ltd., Bakewell)

model for Arkwright's first factory built at Cromford in Derbyshire fifty years later.

It is not within the province of this article to discuss the rival merits of the inventors of mechanical methods of spinning. Whether Wyatt and Paul (1731), Hargreaves (1769), Arkwright (1770), or Crompton (1779) deserves the more credit is beside the point. Arkwright won the prize, and the use of his "Water Frame" (so-called because it was driven by water power) brought undreamed-of prosperity to the new industry.

Arkwright was quick to exploit his invention. He built factories at Bakewell, Birkacre near Chorley, Belper, Nottingham, Wirksworth and New Lanark. Most, if not all, were driven by water power.

Inventions to enable power to be used to assist the cotton industry followed fast during the next few years. Calico printing, carding, and, in 1785, Cartwright's power loom, all increased production in the industry, and made it more and more dependent upon a reliable form of motive power. To quote Paul Mantoux:—

> "The main characteristics of that time (Circa. 1775) was the use of water for motive power . . . This had important consequences, for it meant that no factory could be established far from a stream powerful enough to set the machines in motion. For this reason it was not in towns that the mill-owners first established their factories, but near the hills, in narrow valleys, where, by using dams, it was easy to create an artificial waterfall . . . These small places are scattered along the foot of the Pennine range, on all three sides of it, on the west towards Manchester and the Irish Sea, on the south towards the Trent Valley, and on the east towards the Yorkshire plain and the North Sea." [6]

In 1788 there were 122 spinning mills in England and Scotland, of which 84 were in the area described above, five in Westmorland, and 13 in the Scottish Lowlands.[7]

The first "Rotative" steam engine was used in a cotton mill in 1785, but even by the turn of the century their use in mills was comparatively rare. James Watt, writing to his partner Matthew Boulton in Ireland in November 1782, says:—

> "If you come home by way of Manchester, please not to seek for orders for cotton-mill engines, because I hear there are so many mills erecting on powerful streams in the north of England, that the trade must soon be overdone, and consequently our labour lost." [8]

The demand for water power was not limited to the cotton spinning industry. At Kirkstall Forge near Leeds the Slitting Mill was rebuilt in 1785, and was converted to a plate mill. The following is an extract from a letter to a customer at that time:—

> "We were in hopes from your letter of December 19th that we should have been favoured with your order for Canada plate. It will be convenient for us just now to roll a few tons because we have a good supply of water—and we cannot manufacture thin plate iron so well when our water is short."

The following year there was consternation in the firm when the town of Leeds suggested taking its water supply from the Cow Beck which fed the Kirkstall Abbey Mill Race. Writing to Lord Cardigan's agent they said:—

> "The whole brook runs into our pool Two Fields above our works, which is of great service to us also the favour you granted us by bringing the Brook in the sed Water Corse which once supplied the Abbey will be of no servis to us and we have laid a great deal of money on that Acct., as we are sensable such a Large Town in time of Draught will want the whole brook to supply it with.
>
> We have completed all our works, have taken up and Enlarged all our Races and have got all the wheels new, Pulled down the slitting mill and Erected one above as large agean as the old one the whole Improvement we have Don that belongs to his Grace we estimate it Fourteen Hundred Pounds, besides all our own improvements . . .
>
> What are all these things worth if the water is taken away . . ."

Their appeal prevailed, and water power received preference over water supply. It must indeed have been valuable in those days! [9]

Large forges and ironworks were being built in many parts of the north. The Carron Ironworks near Falkirk was opened in 1760. In 1764 Matthew Boulton built his famous Soho Factory which was driven by the water power of Hockley Brook. Kilnhurst Forge with its four sets of bellows, trip-hammer and tilt-hammer all independently driven by waterwheels was completed in 1765.

In Sheffield, waterwheels were used to grind cutlery and tools, and the abundance of water power contributed largely to its specialised trade. There were a number of small works where a workman rented a "side" or "trough" to carry on his work. In 1770 there were 161 separate works driven by waterwheels on the five rivers and streams of Sheffield.[10] Mr. W. T. Miller carried out a detailed survey of the Sheffield mills, and although at one time and another some of these

mills were not working, the summary in Table I of his researches probably gives a fair estimate of the wheels which were operating for most of the period from 1750 to 1840.

TABLE I
SHEFFIELD MILLS OF THE INDUSTRIAL REVOLUTION

River	From	To	No. of Mills
Don	Oughtbridge	Lady's Bridge	25
Don	Lady's Bridge	Tinsley	12
Sheaf	Totley Forge	Park Iron Works	31
Porter	Fullwood Upper Corn Mill	Pond Corn Mill	20
Rivelin	Uppermost Wheel	Malin Bridge	23
Loxley	Low Bradfield Corn Mill	Nether Slack Tilt	30
Blackburn Brook	Whitely Mill	Blackburn Forge	10
		Total	151

When the Wakefield Waterworks Bill of 1874 was being considered, some 33 properties on the rivers Porter and Don were affected. There were 31 separate falls varying from 4 ft. 0 in. to 17 ft. 6 in., 80 waterwheels (some of which were dilapidated), and one water turbine was described as follows: "This is a turbine, but of little use."[11]

John Somervell considers that most of the industries which grew up in South Westmorland started because water power was available, and Table II gives the essential facts obtained from his two works upon this subject.

TABLE II
INDUSTRIES OF SOUTH WESTMORLAND DEPENDENT UPON WATER POWER

Industry	Location	Date first recorded
Corn milling	General	12th Cent.
Fulling	Kendal	1256
Sickle making	Scroggs Mill, Staveley	1689
Snuff grinding	Near Kendal	1740
Flax	General	1755
Paper making	Milnthorpe and Burnside	1764 1769
Gunpowder	Sedgwick, near Kendal	1787
Iron forge	Force Falls, nr. Kendal	
Cotton	General (6 mills in 1787)	Circa. 1760
Marble mills	Near Kendal	1800
Carding and wire drawing	Kendal	1805
Carpet making	Kendal	1822
Bobbin mills	General	1829
Saw mills	Staveley (sawing sleepers for Oxenholme-Windermere Railway)	1847
Haft making	Staveley	19th Cent.
Comb making	Milnthorpe	19th Cent.
Woollen mills	General	19th Cent.

He traced 112 mills in an area 20 miles by 12, and notes that the first steam engine was introduced to Castle Mills, Kendal, in 1855. Until this date every industry had relied solely upon its water power.[12]

By 1800 the demand for power was such that the rotative steam engine was implementing the waterwheel in all areas where coal was cheap and water power unreliable. There can, however, be little doubt that water power was generally preferred until the latter half of the nineteenth century, and very large sums were still invested in its development.

Dealing with the cotton industry only, Baines, writing in 1835, gives the following picture of the number of mills and the horsepower generated in different areas of the British Isles as estimated by the first four Factory Inspectors to be appointed:—

POWER GENERATED BY WATER AND STEAM IN COTTON MILLS CIRCA 1834

Inspector	Area covered	No. of mills	Horsepower generated by:	
			Water	Steam
Mr. Rickards	Lancashire	657	2831	21387
	Yorkshire	140	1430	956
	Cheshire, Staffs. N. Denbigh, Flint	81	912	3494
	Derby (High Peak)	56	921	676
Mr. Horner	Scotland (Lowlands)	121	2030	3093
	Perth & Aberdeen	4	450	107
	Northern Ireland	15	234	372
	Cumberland	12	78	98
Mr. Saunders	Notts. Derby (S) Staffs. Middlesex	54	1172	438
Mr. Howell	Not stated	14	146	232
	Total	1154	10204	30853

It will thus be seen that fifty years after the steam engine was first used in a textile factory, one-third of the power was still generated by water. Eliminating Lancashire, the 497 remaining cotton mills used 7,473 horsepower of water and 9,466 horsepower of steam.[13]

The Early Factory Waterwheels

It is fortunate that many of the mechanical drawings of John Smeaton, F.R.S. (1724-1792) have been preserved, and these give us an excellent idea of the construction of waterwheels during the latter half of the eighteenth century.[14] He realised the importance of obtaining the maximum efficiency from his waterwheels and in 1752-3 he carried out a number of experiments on model waterwheels which evidently had a considerable influence upon design for at least a hundred years.[15] These experiments were carried out with both undershot and overshot wheels, and Fig. 3 shows the apparatus which he used.

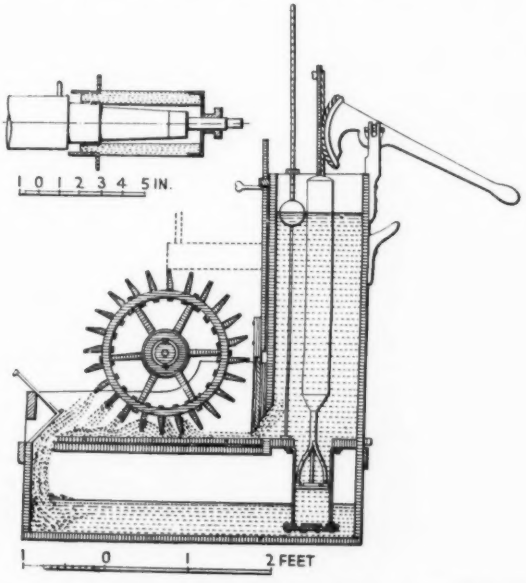


Fig. 3. Section of model waterwheel upon which John Smeaton carried out his tests

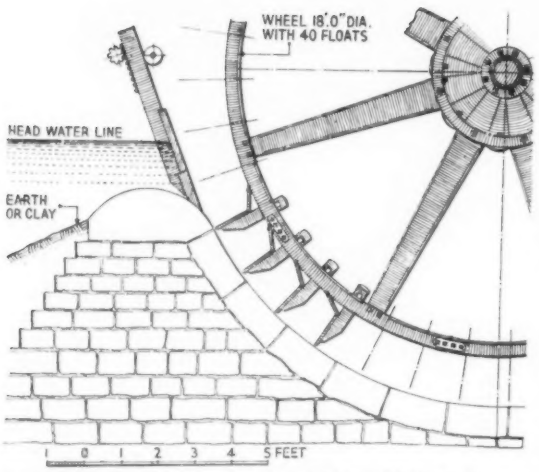


Fig. 4. Breast Wheel for the Boring Mill at Carron Ironworks
(Reproduced by permission of the Royal Society)

The wheel was supplied with water from a wooden tank under a constant head. The rate of flow of water was measured by the number of strokes of a pump of known dimensions required to maintain the head of water in the tank. The power output was measured by taking the time to lift a weight a given height. Smeaton concerned himself mainly with what might be termed the "Hydraulic Efficiency" of the wheel, and made a number of corrections to compensate for friction and head losses which could not be accepted in the tests of a modern hydraulic prime mover.

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Fig. 4 shows the low breast wheel which he built to drive the boring mill at Carron Ironworks. All the motive power for this famous works was provided by Smeaton's waterwheels, and in Table III is a list of the essential plant installed.

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Description	Number of wheels	Date of design
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Boring mill - - - - -	2	1770
Blacking and grinding mills -	1	1770
Clay mill - - - - -	1	1777
Tilt hammer forge - - -	1	1785
Bretton Furnace Wheel -	1	Undated

Water was drawn from the River Carron, and the total head available was about 30 feet. A storage reservoir was built, but considerable care must have been required to ensure that the best use was made of the water to operate all wheels to obtain maximum production. When water was short the works manager must have had a difficult time trying to satisfy all his departmental foremen! A drawing dated 1780 is a "General plan for the 'Returning Engine' at Carron." This was evidently a Newcomen engine used for pumping the water discharged from the waterwheels back to the head pond. It was common practice at this time to use Newcomen pumping engines for this duty. One was installed at Boulton and Watt's Soho factory for use when the power requirements of the factory exceeded the dry-weather flow of Hockley Brook.[17]

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The Larger Waterwheels

Before Smeaton's day waterwheels had been constructed almost entirely of wood; this is one reason why, apart from his drawings, we have so few records of the old wheels. They were slow moving, heavily stressed and continually "wet and dry." The wear and tear was heavy, and factory owners with an expanding business could not afford to keep patching old and inefficient wheels. Smeaton realised this, and introduced first a cast iron wheelshaft (1778) and later wrought iron buckets (1780). Cast iron plates were used to join up the wooden sectors of the shrouds, and when it was found that there was no need to transmit the full power of the wheel through the shaft, but that a gear wheel could be built on to the shroud of the waterwheel, thus transmitting the power to a

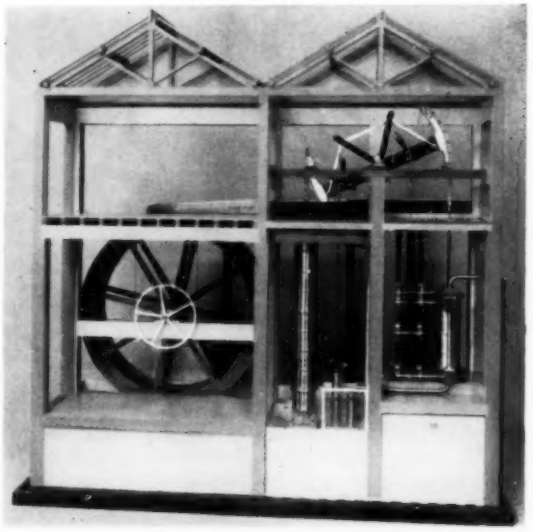

Fig. 5. "Old Bess," the beam engine erected by James Watt at Soho in 1777 to return tail water to the waterwheel in times of drought
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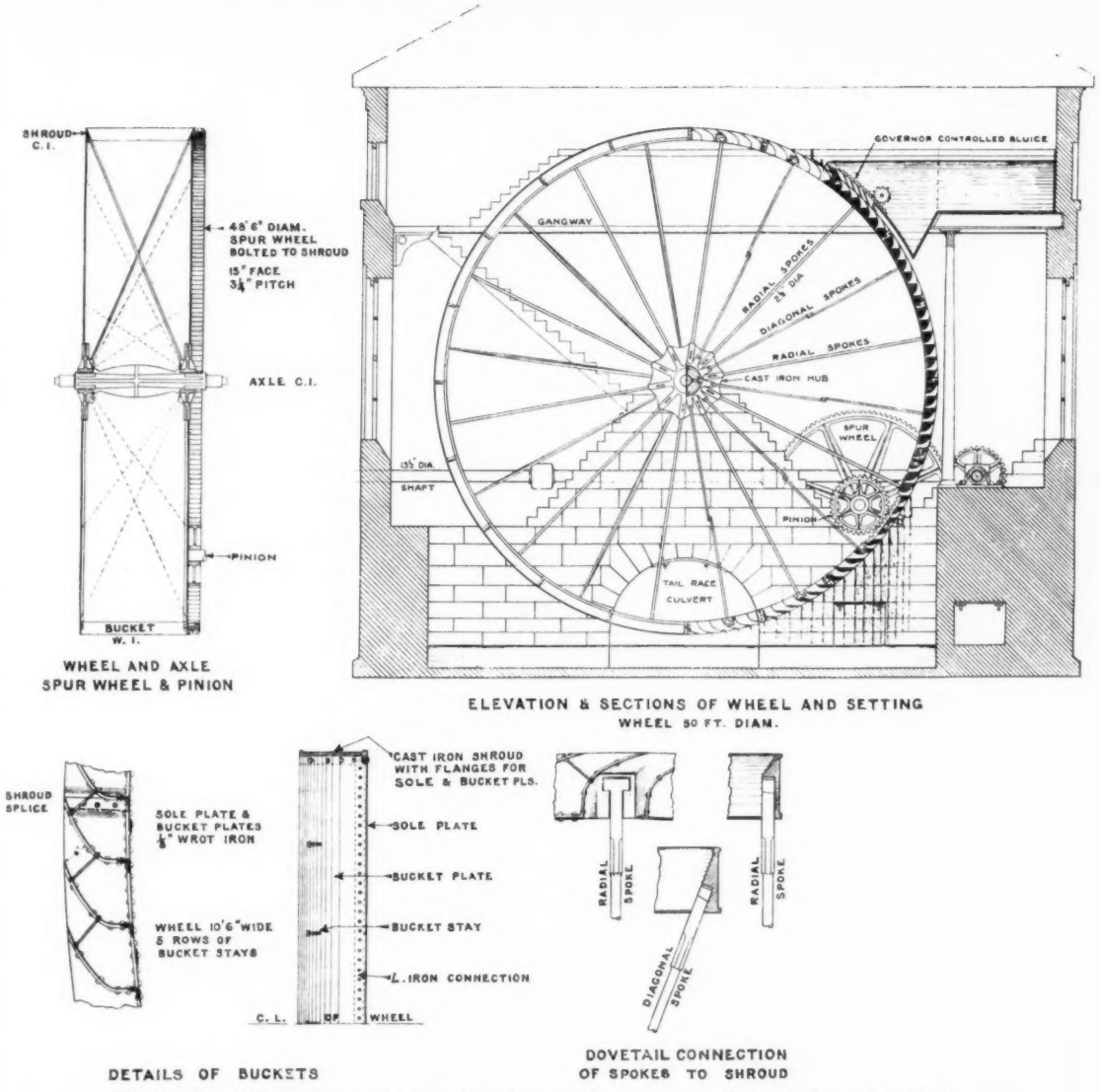

Fig. 6. Two 250 B.H.P. waterwheels at the works of James Finlay & Co. Ltd., Catrine. Designed by Sir William Fairbairn

(Reproduced by permission of James Finlay & Co., and Mr. James Williamson, M.I.C.E.)

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The form of construction adopted was usually along the lines indicated in Fig. 6. This is particularly interesting as it is a modern drawing of wheels built 126 years ago. It was made by James Williamson, M.I.C.E., when the Catrine Mill wheels were dismantled in 1947 to be replaced by modern water turbines. It will be seen that the shaft was of cast iron, with wrought iron radial and diagonal spokes which were kept in tension. Each wheel was 50 ft. 0 in. diameter by 10 ft. 6 in. wide and developed 250 B.H.P. Two spur wheels with internal teeth transmitted power to an intermediate shaft which in turn drove the mill. The shrouds were of cast iron and the buckets of wrought iron.

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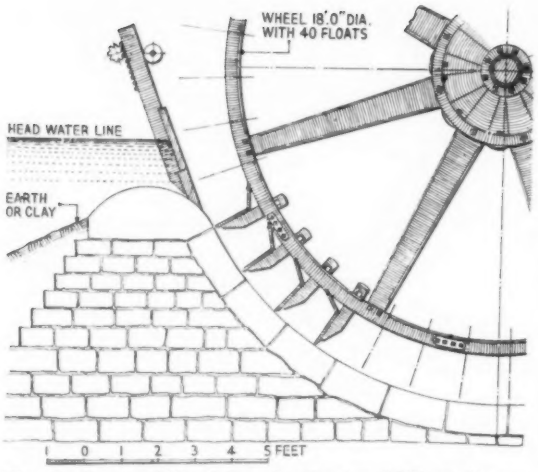

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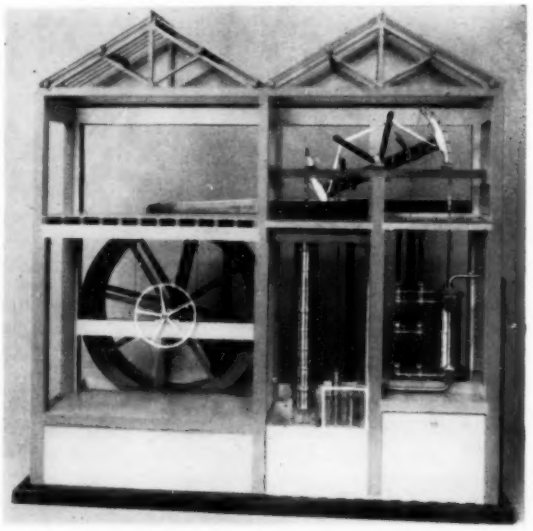

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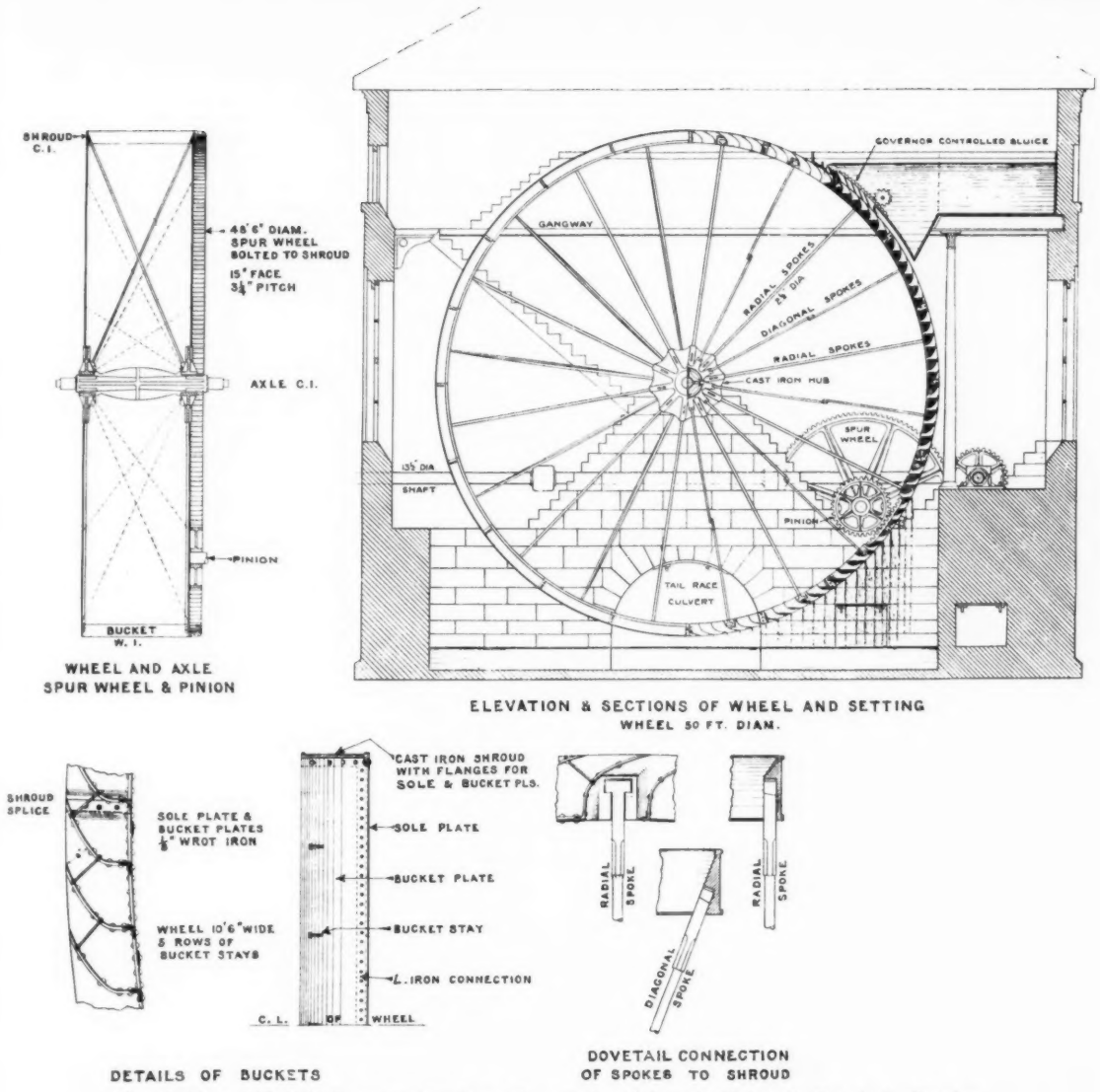

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TABLE IV. LARGE WATERWHEELS OF THE NINETEENTH CENTURY

Date built	Feet dia.	Feet wide	Estimated output B.H.P.	Designer and/or manufacturer	Where installed	Remarks	Ref.
1827	50	10·5	250	Sir W. Fairbairn	Jas. Finlay & Co., Catrine, Ayr	Two wheels installed, see Fig. 6. Dismantled 1947 and replaced by turbines	19
1827	25	18	88	Hughes and Wren	The D. P. Battery Co. Ltd., Bakewell, Derbyshire	This, and a smaller wheel 21 ft. diameter, is still working, see Fig. 2. The site is that of Arkwright's factory	20
C. 1830	20	22	70	Sir W. Fairbairn	Thos. Ainsworth, Cleator, nr. Whitehaven		21
C. 1830	70	12·5	190	Jas. Smith, Deanston	Shaw's Cotton Spinning Co., Greenock	One of the waterwheels supplied from Shaw's Waterworks (described on this page)	22
1831	36	10·9	C. 90	Sir W. Fairbairn and Jas. Finlay	Jas. Finlay & Co., Deanston, Perth	Fairbairn built two wheels and Jas. Finlay two more later. They were dismantled in 1949 and replaced by turbines	23
C. 1840	51	10	87		Wheal Friendship Mine, near Tavistock	Used for mine dewatering	24
1854	71	6	231	Gt. Laxy Mining Co.	Gt. Laxy Mining Co., Isle of Man	Used for mine dewatering. Mine abandoned in 1929 but wheel still standing and on view to tourists	25
C. 1855	40	12	C. 90	Mr. Smith, Great Devon Consolidated Copper Mines	Great Devon Consolidated Copper Mines, near Tavistock	In all there were twelve waterwheels at these mines, mostly on the river Tamar. They were used for dewatering the mine and driving the milling plants	26
1864	57·5	12	240	Taylors of Marsden	Rishworth Mills, near Halifax, Yorks.	The wheel weighed 70 tons and is reported to have been made up of 29,300 pieces. Dismantled in 1949 and replaced by a turbine	27

Water Power Improvement Schemes

During the first half of the nineteenth century the millowners were not convinced that only steam power would be their salvation. It seems probable that there was a strongly conservative element amongst them who had infinite faith in the superiority of water power. The simplicity of the waterwheel and the fact that once installed it is "power for nothing" has always had a strong appeal, and the coal bills may have been more irksome than the electricity bills of the modern factory, to which manufacturers have become accustomed.

The earliest and one of the most important schemes for providing a continuous supply of water to the mills throughout the year was "Shaw's Waterworks" for the supply of power and domestic water to the town of Greenock. These works were designed by Mr. Thom, and in his report on the scheme he stated that the supply of water available for the mills would be "to an extent at least equal to all the machinery then (in 1824) impelled by steam power in Glasgow." The principal works were completed in 1827 and comprised three reservoirs having areas of 295, 40 and 10 acres respectively. A water course six miles long was built, and a supply of some 20 cusecs was guaranteed to the mills. A total head of 512 feet was developed, and one of the main features of the scheme was that the water was brought to the populous town of Greenock instead of the mills having to be built in isolated places where water power was available. It was claimed that sufficient storage could be provided to supply the mills for six months during a dry season.[28]

In 1836 Mr. J. F. Bateman and Sir William Fairbairn were consulted upon the best means of regulating the flow of the River Bann in Northern Ireland upon which there were a large number of mills. Mr. Bateman built the Lough Island Reavy reservoir in the mountains of Mourne, enlarging a small lough to an area of 253 acres and giving a storage of 287 million cubic feet with a draw-down of 40 feet. A secondary scheme involved the construction of Corbet Lough having an area of 74½ acres and a capacity of 47 million cubic feet. Fairbairn calculated that there was a fall of 350 feet from the lowest drawdown level to the lowest mill on the river, and with a flow of 40 cusecs 1,166 horsepower could be developed by the millowners.[29]

One of the most ambitious schemes for the benefit of the millowners was that produced in 1844 by Mr. Bateman for the River Kent and its tributaries, the Mint and Sprint. Had it been carried through, this would have involved the construction of six reservoirs having an area of 486½ acres and a capacity of 304 million cubic feet. The full level altitudes of the reservoirs would have varied from 1,025 feet to 700 feet A.O.D. and Mr. Bateman estimated that the millowners could rely upon a normal output of 7 B.H.P. per foot of fall on the rivers. His plan indicates 21 mills on the rivers concerned but John Somervell expresses the opinion that had the scheme gone through many more would have been set up.[30]

The Kentmere Head Reservoir was built, but at a cost considerably exceeding Bateman's estimate. By that time (circa. 1850) the millowners evidently decided that the cost of further reservoirs would not be justified and nothing more was done.[31]

According to Baines a similar scheme was proposed for the River Irwell, upon which, he states ". . . from the first mill near Bacup, to Prestolee, near Bolton, there is about 900 feet of fall available for mills, 800 of which is occupied. On this river and its branches it is computed that there are no less than three hundred mills."[32] Reservoirs were planned having an area of 270 acres and designed to store 241 million cubic feet giving an estimated power on the river of 6,600 horsepower.

The Decline of Water Power

By 1850 it can be said that water power had no decisive influence upon the development or location of industry. Some large waterwheels and an increasing number of turbines were built and installed after that date, but the steam engine had become the generally accepted prime-mover.

The decline in the importance of water power was not altogether a *relative* decline due to the ascendancy of the steam engine. According to Fairbairn the potential run-of-the-river power was decreasing throughout the nineteenth century. Writing in 1864 he says:—

> "At the commencement of the present century, when the land was imperfectly drained, the soil and surrounding marshes, having no outlet, retained and stored up the rainfall, and became the great holders or reservoirs by which the waters were impounded, and the flow of our rivers regulated with greater uniformity than at present. Since the introduction of an extended system of drainage the whole character of our rivers has been changed, and now discharge their contents with much greater rapidity and in larger volumes than they were accustomed to before these improvements were introduced. The result of this has been favourable to the land but injurious to the mills, both as regards uniformity and the loss of power, as nearly one half of the supply is carried off by floods and cannot be retained for the use of the mills. In all districts of the country where drainage and an improved system of tillage have come into operation, the effect has been a serious loss to the owners of water mills, and has driven most of them to the use of steam, either as an auxiliary, or in some instances exclusively as a substitute for water."[33]

Fairbairn's statement is sweeping, but probably contains some truth. A further factor was the steadily increasing diversion of water from the higher districts to supply the domestic needs of the new towns. By 1900 a substantial proportion of the rainfall in many catchment areas was being diverted to domestic supply, and although the millowners fought hard for their compensation-water rights, they could usually be persuaded to give way knowing that alternative sources of power were available.

All these factors sink into insignificance compared with the enormous increase in the demand for power. In 1750 a well known consulting engineer would be called in to discuss a proposition involving the construction of a mill developing 5 or 10 horsepower for perhaps nine months in the year. By the time of the Great Exhibition (1851) steam engines and boilers could be had from dozens of manufacturers, and a useful supply of water power became a luxury and not a necessity.

Water power has played a great part in Britain's industrial development, and while for a hundred years it has been held in low regard, the time is again coming when the riparian owner who has kept his water rights, weirs and races in good order may well be glad to exploit the natural tendency of water to seek a lower level in order to reduce his bills from the national grid.

1 Paul N. Wilson, "*The Origins of Water Power.*" WATER POWER, August 1952, pp. 308-313.
2 A. P. Wadsworth & J. de L. Mann, "*The Cotton Trade and Industrial Lancashire 1600-1780.*" Manchester University Press, 1931, pp. 148-161.
3 It is interesting to reflect that "Horse Power" is now frequently referred to in thousands or millions, but when James Watt defined a "Horse Power" as 33,000 ft. lb. per min. horses were probably only exerting a small fraction of the motive power used in Britain at that time.
4 Paul Mantoux, revised by Marjorie Vernon, "*The Industrial Revolution in the Eighteenth Century.*" Jonathan Cape, London, 1928/47, p. 258.
5 Mantoux. Op. Cit., pp. 197-201.
6 Mantoux. Op. Cit., pp. 252-4.
7 John Somervell comments upon the remarkable fact that these cotton mills disappeared from Westmorland at a comparatively early late. None are mentioned in the Factory Inspector's report quoted by Baines in 1835. (See p.—) John Somervell, "*Water Power and Industries in Westmorland.*" Trans. Newcomen Soc. Vol. XVIII, 1937-8, pp. 235-244.
8 Samuel Smiles. "*Lives of the Engineers.*" John Murray, London, 1862, Vol. IV, p. 327.
9 Rodney Butler. "*The History of Kirkstall Forge.*" Hy. Jenkinson Ltd. Kirkstall 1945, p. 15.
10 "*An Industrial Museum for Sheffield.*" The British Steelmaker, April 1941, p. 75.
11 W. T. Miller. "*The Water Mills of Sheffield.*" Pawson & Brailsford, Sheffield. 1949.
12 John Somervell. Op. Cit. and "*Water Power Mills of South Westmorland.*" Titus Wilson & Sons, Kendal, 1930.
13 Edward Baines, Jnr. "*History of the Cotton Manufacture in Great Britain.*" London, 1835, pp. 386-394.
14 "*Smeaton's Designs.*" Newcomen Society, London, 1950. A catalogue of the Civil and Mechanical Engineering Designs of John Smeaton, preserved in the library of the Royal Society.
15 John Smeaton, F.R.S. "*Experimental Enquiry Concerning the Natural Powers of Wind and Water to Turn Mills, etc.*" London, 1794. The papers were read to the Royal Society on May 3rd and 24th, 1759, but Smeaton states that the experiments were carried out in 1752/3. See also Jos. Glynn. "*On the Power of Water to Turn Mills.*" John Weale, London, 1853, Ch. IX. "These papers were long considered as the text from which millwrights should deduce their rules of practice, and even now they well deserve careful study of those who engage in the construction of such machines with the later experiments of Rennie, Morin and Poncelet." Sir Wm. Fairbairn writing in 1878 confirms this statement.
16 Samuel Smiles, Op. Cit., Vol. 2, p. 73.
17 Mantoux. Op. Cit., p. 325. "Newcomen's engine could, without great alterations, have been made into a driving engine . . . . though the idea was easy to apply it was not turned to any practical use, as it was found simpler to pump up water into a reservoir, and then use it to turn a wheel. About the middle of the eighteenth century this combined use of the fire engine and water-wheel was found everywhere."
18 John Rennie. "*Experiments on the Power of Water Wheels.*" Quarterly papers on Engineering, 1845.
19 James Williamson & Partners. Edinburgh.
20 The D.P. Battery Co. Ltd., Bakewell, Derbyshire.
21 Fairbairn. Op. Cit., p. 134
22 "*The Engineer & Machinist's Assistant.*" Blackie & Sons, London, 1847, Plates LXXXVIII & IX.
23 Sir William Fairbairn. "*Treatise on Mills & Millwork.*" London, Longman's Green & Co., 1878, p. 126.
24 Proc. Inst. Civil Engineers, 1842.
25 Drawing by A. Jespersen, Odense, Denmark, by permission of the Science Museum, South Kensington.
26 Mining Journal, 1860, XXX p. 518.

(Continued overleaf)

[27] John Crossley & Sons Ltd. Dean Clough Mills, Halifax.
[28] Joseph Glynn. "*On the Power of Water on Turn Mills.*" John Weale, London, 1853, pp. 28-30.
[29] Sir Wm. Fairbairn. Op. Cit., pp. 75-79.
[30] John Somervell. "*Water Power Mills of South Westmorland.*" p. 14.
[31] J. F. Bateman. "*Report & Plans for Kendal Reservoirs.*" 1844. Kentmere Reservoir Commissioners. It is interesting to note that the watersheds of the three rivers in question are amongst the few in the north-west of England which have not been tapped for water-supply purposes. At date, of the potential 900 feet head from Kentmere reservoir to sea level, a distance of only 23 miles along the course of the river, only 61 feet head are used for power, the maximum capacity of the plant being 386 horsepower. On the tributary rivers Mint and Sprint 345 horsepower are developed, using an approximate head of 80 feet on the rivers.
[32] Baines. Op. Cit., p. 85.
[33] Fairbairn. Op. Cit., p. 66.

Harland-Morgan Smith Rotovalves

After a period of pilot production the Harland Engineering Company Ltd. have now begun to manufacture Rotovalves in a range of standard sizes up to 72 in. dia., under licence from the S. Morgan Smith Company of the U.S.A.

The Rotovalve is essentially a plug cock, and consists of three major components—a body, a plug, and an ingenious operating mechanism, in which its chief interest lies. The body is slightly tapered internally to receive the plug, which is conical. This mechanism actuates the plug axially for seating and unseating, so that when it revolves the plug through 90° for opening and closing there is no contact between body and plug. As a result, no face-to-face frictional resistance has to be overcome, and a self-cleaning action automatically takes places between the body and the plug.

Monel-metal seats are fused to the parent metal of

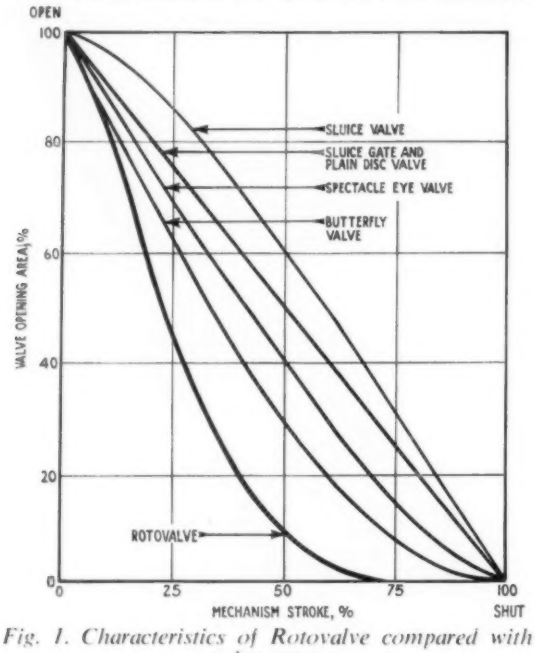


Fig. 1. Characteristics of Rotovalve compared with other types

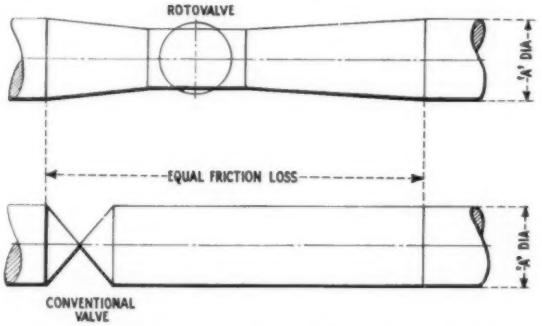


Fig. 3. Rotovalve compared with conventional valve for equal friction loss

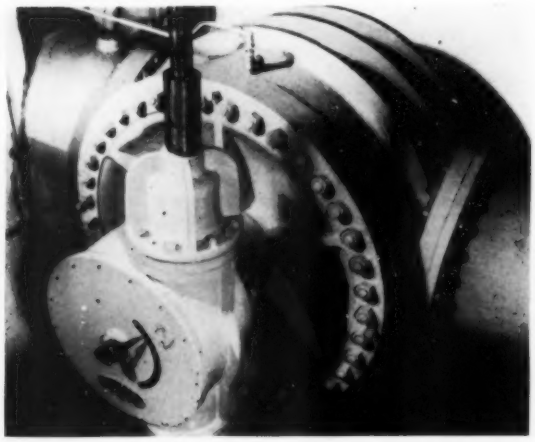


Fig. 2. Rotovalve for Lower White River hydro-electric scheme

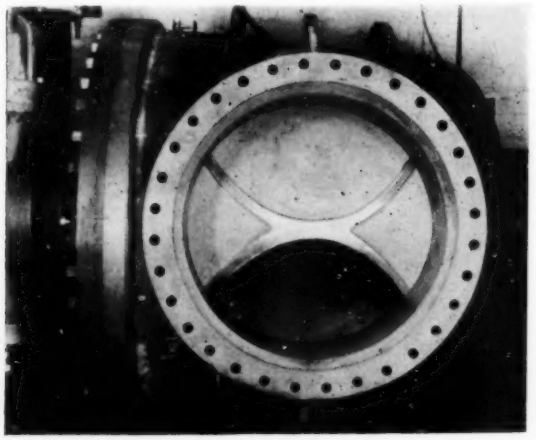


Fig. 4. Rotovalve partially opened, showing construction of plug

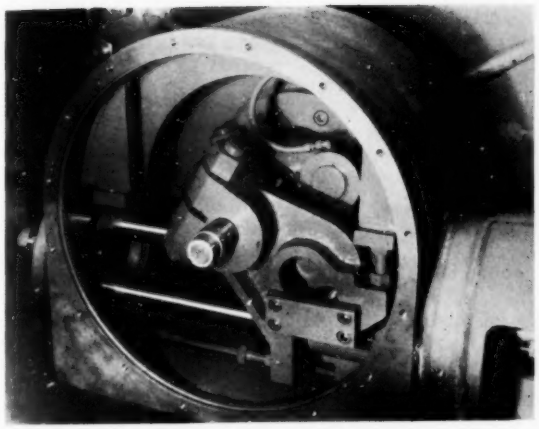


Fig. 5. View of operating mechanism, which provides automatic unseating and seating movements

both body and plug in such a way that the seats are in contact only when the valve is either fully open or fully closed. Both body and plug have circular ports so that when aligned in the open position there is free, smooth, unobstructed flow from flange to flange. The loss in head through the valve is therefore that of a straight piece of pipe of equal bore and length.

Three bearings are employed to provide exact alignment at all times of the body, plug, and operating mechanism. This, together with the facts that bearing pressures are kept low and that the valve seats are clear during rotation of the plug, means that the valve can be opened and closed easily and quickly against full unbalanced pressure. There is no need for a bypass valve or other pressure-equalising device across the valve, and control and operation are consequently simplified.

As will be gathered from Fig. 1 the valve has an important anti-water-hammer characteristic. When closing, 80 per cent. of the port area is cut off in 40 per cent. of the crosshead stroke; thereafter the rate of closure decelerates although the crosshead is moving at a uniform speed. This feature is of course inherent, and no external retarding devices are used to achieve it.

The valves may be opreated by hand, by electric motor or by hydraulic or pneumatic servomotor, depending upon the size, site and other conditions.

Fig. 5 shows the operating mechanism; when the handwheel is rotated, thus raising the crosshead, the lift nut is also rotated, but as it is prevented from moving axially, the plug is raised and so unseated. With the continuing movement of the crosshead the roller engages the rotator lever. The lift nut and rotator lever then operate together, resulting in the rotation of the plug. Towards the end of the crosshead stroke, the lifter lever ceases to move as its connecting link passes over a dead-centre position. The lift nut is thus stationary; but as the rotator continues to turn, the plug shaft moves down the lift nut thread until the plug is reseated in the fully open position. When closing, the reverse sequence of events takes place.

In the case of a motor-operated Rotovalve, the motor replaces the handwheel, but where a hydraulic or pneumatic servomotor is employed, the piston rod connects directly to the crosshead and replaces the screw stem.

It will be noted that unseating, rotation, and reseating of the plug are achieved with one simple straight-line mechanical movement of the crosshead, thereby obviating the need for separate operating and protective devices normally necessary.

It is claimed that as the friction loss through a Rotovalve is considerably less than that of a conventional valve of the same size, a smaller size can be used. The valve can thus be made to form the throat of a venturi section which can thus be made available for flow measurement and control purposes, Fig. 3, experience having shown that equal losses occur when the Rotovalve is approximately 70 per cent. of the diameter of a sluice valve.

Where only hand operation can be justified, quick and easy closing and opening, against full unbalanced pressure, can be effected by only one man, and as the operating mechanism can be completely sealed in oil the valve can be buried directly in the ground without the need for an underground chamber.

The power-driven types, either electric or hydraulic, can combine with their normal isolating duties an over-velocity feature to isolate pipelines automatically in the event of a break. Positive valve timing, vital for controlling water-hammer and low friction loss, are other claims made for this valve. The independent timing of opening and closing, adjustable over a wide range, does not affect automatic operation. If necessary, a composite control can be supplied to give different speeds of plug movement. In all cases, the automatic controls are so arranged so that they can be operated manually in an emergency.

Large Regulating Gates

The Dominion Bridge Co. Ltd. has supplied and erected two of what must be the largest hydraulic control gates and hoists in the world. These gates are used at the entrance of the two 50 ft. dia. tunnels which carry the water from the river, under the city

One of the Dominion control gates at Niagara Falls

of Niagara Falls, Ontario, to the head pond of the Adam Beck No. 2 power plant at Queenston. They are designed to cut off the water to the tunnels at full flow in case of an emergency and to act reliably after long periods of inaction, which might amount to several years.

Model studies were carried out by the Hydro Electric Power Commission of Ontario to determine the lifting loads arising from the hydraulic conditions, when opening and closing the gate. In addition, the hydraulic effect on the tunnel was studied and this resulted in the choice of a lowering speed of only 4½ in. per min. A screw-type hoist was specified, in spite of its increased cost, in preference to the rope type, largely because of the infrequent service. It was felt that if internal corrosion of the ropes took place, it might not be discovered until a disastrous accident occurred.

Operating against a head of 56 ft., each gate is 58 ft. high, 45 ft. wide and weighs about 225 tons. The hydraulic load is transmitted to the embedded steel frame by 42 in. dia. fixed angle rollers with crowned faces and grease-lubricated bronze bushings. Basically the gate is of riveted construction, but certain portions, such as the top lifting lugs, are fabricated by welding. Field joints are riveted and caulked where necessary, rather than welded, to avoid any risk of distortion in the structure, which would upset the careful shop assembly and alignment of all parts.

The gate is raised and lowered by a pair of 10 in. dia. rotating steel screws, 71 ft. in length, manufactured by the Camden Forge Company, who also made the bronze lifting nuts to match. Bronze lifting nuts supported in forged steel trunnions, carried in the lifting lugs on each side of the gate, transmit the load into the screws. Machinery to rotate the screws is located in a fixed structural steel arch above the gate opening. A 40 h.p. electric motor drives cross shafts leading to each end gear, through a central grease case. The end gear cases, containing spur and bevel gears which rotate the screws, also house heavy roller thrust bearings, which take the lock from the screws. All shafts are carried in ball or roller bearings.

The structural steel arch is 75 ft. high and is sheathed in aluminium, which reduces weight and has the added advantage of being rustproof, thereby eliminating the need for periodic painting. Two sets of steel stop logs are also furnished for the tunnel, and are of welded steel construction, with rubber seals, to provide tight joints. Embedded steel checks for these logs are installed upstream from the control gate and also at the downstream exits of the tunnels. This enables the tunnel to be completely unwatered for inspection and repairs.

Abstracts from the World Technical Press

Pump-Turbine at Flatiron

The latest addition to Bureau of Reclamation's hydro units is described, this being a pump-turbine that has just gone on the line at the Flatiron plant of the Colorado—Big Thomson project near Denver. It can either pump up water from the station's afterbay, at slack periods, through more than a mile of pressure tunnel and 1,700 ft. of pressure conduit into the 112,000 acre ft. Carter Lake Reservoir, or produce profitable power at peak periods. As a pump, the unit has a rated capacity of 370 cu. ft. per second at a lift of 240 ft., requiring a 13,000 h.p. motor for the drive; when reversed as a turbine-generator, the rating is 8,500 kW. The other two units of the plant have conventional 31,500 kW water turbines using a head of about 1,100 ft. With Flatiron Plant now in operation, the whole project comes very close to being completed. The only major jobs to be done are three main canals to be excavated along the eastern side of the supply works. (*Electrical World*, Vol. 41, No. 13, pp. 42/43, 3 ff.)

Dupuit's Formulae

Dupuit's "Dam or Drain Formula" and "Well Formula" are closely examined in the light of the recent demonstrations contributed by Charnyi in a paper presented to the Soviet Academy of Sciences in Moscow, in July 1951. The author first recalls that the first formula enables the discharge passing through a homogeneous porous mass of rectangular cross-section to be calculated while the second applies to the discharge collected in a vertical well of circular cross-section in the middle of a homogeneous porous mass, resting in both instances on a horizontal impervious substratum. Charnyi's demonstration rests essentially on the application of Leibnitz's rule (derivation under the integral sign) to an integral depending on a parameter on which also depend the integration limits. The formula applying to each case is thoroughly analysed and, while the demonstration can be accepted as strictly correct from the mathematical standpoint, the author contends that it does not exhaust the problem in all its aspects, since it implies the existence *a priori* of a resurgence zone through which the flow passes. An advantage of Charnyi's process lies in the fact that it avoids the difficulties inherent in the integration of Laplace's equation but his demonstration lacks selectivity inasmuch as it can very well make shift with erroneous data. (A. Vibert, *Le Génie Civil*, Vol. CXXXI, No. 1, 1.1.1954, p. 10/12, 3 ff.)

Ala Development, Italy

The Ala hydro-electric plant, in the Adige valley south of Trento, is a typical run-of-river installation which turns to good account the partial regulation of the river provided by a succession of large reservoirs upstream. Before entering the pressure tunnel, the water utilises the diversion works of the Mori plant and, after feeding a 50,000 kVA power house returns to the river some 12 km. downstream from the intake. This development comprises the following main works:—

The old barrage and intake, with four 16·5 m. × 6 m. Stoney gates, flanked on the right bank by thirteen 6 m. intake gates. The old diversion canal, utilised throughout its whole length, which connects with the new pressure tunnel 9,250 m. in length, 66 sq. m. in wetted cross-section, and a slope of 0·45 per cent.

The underground forebay, 5,000 sq. m. in area, with a surge chamber at its downstream end; this forebay connects with the pressure tunnel through three shafts

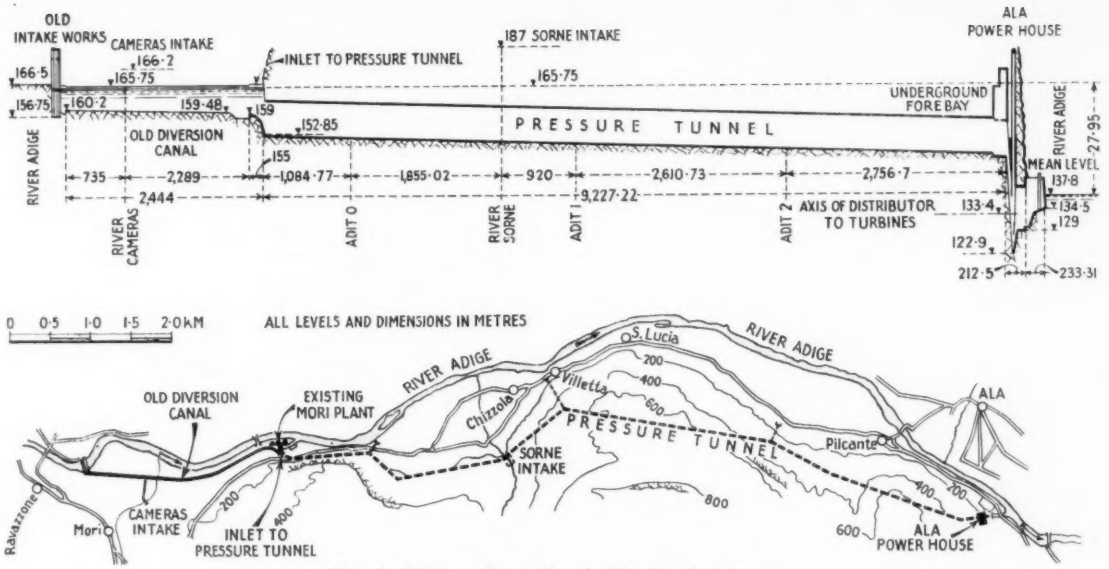


Fig. 1. Map and profile of Ala development

9·5 m. in diameter. Two ferroconcrete penstocks 5·6 m. in diameter. The underground power house, reaching about 100 m. deep into the rock, 42 m. × 13·5 m. by 18·7 m. in height, with an overall height of 39 m. from the bottom of the draught tubes to the crown. The tailrace works, with two 130 m. long discharge tunnels 8·7 m. in diameter, which connect with a 200 m. open canal leading to the river. The outdoor switchyard and transformer station.

The power house shelters two vertical-axle generating sets consisting each of an alternator (Tecnomasio Italiano Brown-Boveri, Milan) driven by a Kaplan turbine (Costruzione Meccaniche Riva, Milan), with the following characteristics:—

Turbines:	min.	max.
Net head (m.)	20·9	27·8
Discharge (cu. m.)	100	100
Nominal power (kW)	17,860	24,260
r.p.m.	167	167
Efficiency guaranteed at 8/10 of maximum load (per cent.)	89·5	90·5
Alternators:		
Nominal continuous rating (kVA)		25,000
Voltage (± 10 per cent.)		10,000
Frequency (±5 per cent.)		50
Number of poles		36
Moment of inertia of revolving masses (tm²)		3,500

The outdoor high-tension equipment comprises two

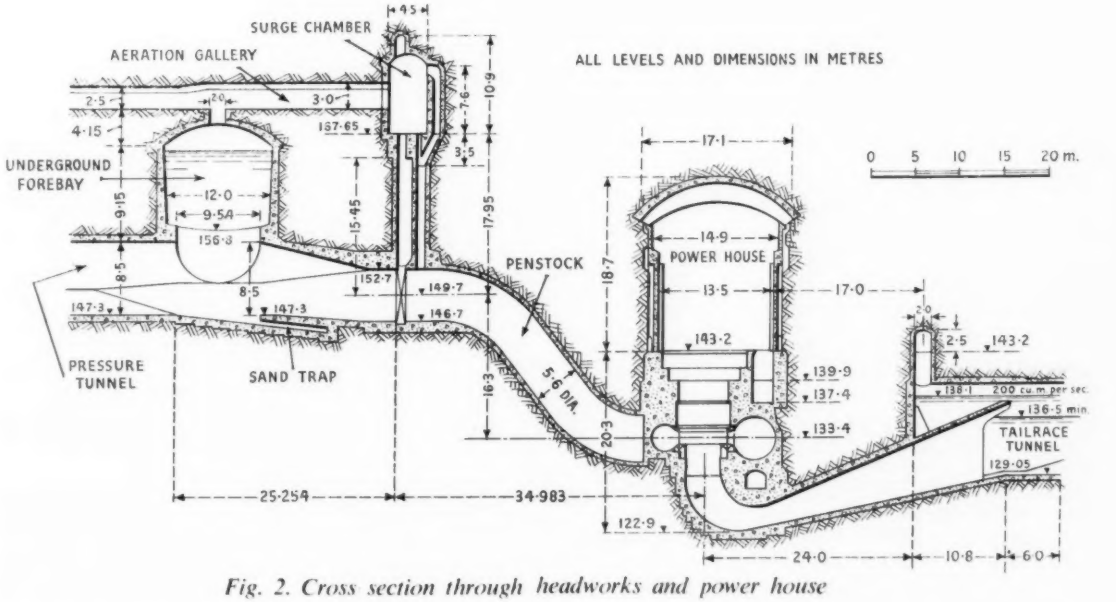
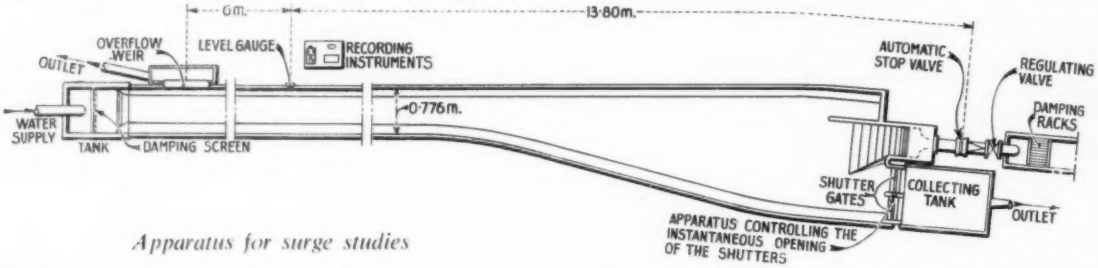


Fig. 2. Cross section through headworks and power house

step-up transformers 10/130/225 kV, rated at 25,000 kVA, feeding two 130 kV three-conductor systems of the Societá Montecatini and a 225 kV 3-conductor system of the Societá Selt-Valdarno; provision is made for future addition of a 130 kV and a 225 kV system. The Brown-Boveri circuit breakers are of the compressed-air DCF type. All controls are concentrated on a switchboard in a room adjacent to the machine hall. (*L'Energia Elettrica*, Vol. XXX, No. 11, Nov. 1953, p. 763, 14 pp., 19 ff.)

Surge Studies

A detailed report is given of an interesting series of tests carried out at the Laboratory of Hydraulics of the Milan Politecnico on a 1 : 30-scale model of the Tornavento power plant and its associated supply canal. The main purposes of these tests was to determine the characteristics of the surge caused in the supply canal by the closure of the turbine, and the effect on that surge of the sudden lowering of the shutters of the weir. The experimental model, shown in the accompanying diagram, is described, and the results obtained by a special level recorder, fitted in the canal, are expounded and discussed. The conclusion arrived at is that the action of the gates is to stabilise the height decrease of the crest of the surge as determined by the pattern of the supply canal acting as a forebay, whose width at the downstream end is about three times the normal width of the supply canal. (Prof. Ing. Giulio de Marchi, *L'Energia Elettrica*, Vol. XXX, No. 12, December 1953, p. 803, 19 pp., 17 ff.)



Apparatus for surge studies

Electric Welding of Penstocks

The techniques applied nowadays to the manufacture and assembling of high-pressure penstocks have been repeatedly reviewed and discussed by the author with particular stress on the progress achieved in recent years in weight reduction and improved reliability. The problem is approached in this article from new aspects, proceeding from wide ranges of experiments carried out by Curio Fornaci in Italy and by the author himself in France; the purpose of these tests was to ascertain the mechanical qualities of certain grades of steel especially selected by penstock manufacturers because of their excellent performances. It is surprising how the steels now used in penstocks can stand the stresses to which they are submitted, and how modern welding techniques can produce joints which offer at least as much resistance to bursting as the penstock proper. From the test charts and diagrams submitted by steel manufacturers the experiments appear thoroughly conclusive, and it is beyond doubt that, thanks to electric welding, steels with a high elastic limit can now be safely used. The results obtained in these tests show a remarkable regularity, and are no less conspicuous from the wear and tear aspect; electrically welded penstock joints are indeed proving no less strong, if not stronger, than the penstock itself. (G. Ferrand, *La Houille Blanche*, Vol. 9, No. 1, January-February 1954, p. 43, 14 pp., 7 ff.)

Working Life of Turbine Runners

Wear is the main efficiency-reducing factor in turbine runners, and not only results in energy losses but also the cost of new runners and the possibly heavy financial losses incurred during dismantling and refitting. Proceeding from these facts, the author attempts to calculate the optimum working life of turbine runners. The importance of such a computation is particularly obvious in the case of quick-wearing runners, such as Pelton wheels at high heads or any turbines that are powered by water carrying a high proportion of sand or gravel. The ageing of a turbine through wear has not the same importance in run-of-river plants as in storage plants; in the former, the decrease of energy production only, irrespective of water consumption, enters into account, while in the latter, the energy of the water not used remains in storage in a variable-level reservoir. Run-of-river plants may however also operate from a variable head at low-water periods and the author prefers to restrict the bases of his computations to two theoretical instances:—

(1) Unlimited supply of power water which enables the energy losses due to discharge by by-pass to be ignored.

(2) Availability of storage facilities which enable the water to be kept in reserve for later requirements.

Formulae for computing the immediate financial loss in both instances are followed by the calculation of the runner's operating life; the respective values of the coefficients representing the loss of energy due to wear and the drop in efficiency are then determined and compared. The article concludes with a numerical application of the formulae to the case of turbine in a specified run-of-river plant. (M. Daniel, *La Houille Blanche*, Vol. 9, No. 1, p. 57, 7 pp.)

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